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Exploring the optimal plateau durations of tone burst to elicit masseteric vestibular evoked myogenic potentials: a within-subjects study

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Abstract

Objective The purpose of the present study was to explore the effect of plateau duration in eliciting masseter vestibular evoked myogenic potentials (mVEMPs) in healthy individuals with hearing sensitivity ≤ 15dBHL.

Method A within-subjects design was utilized in the study. Therefore, ipsilateral tone burst evoked mVEMPs were obtained from 30 healthy individuals using the zygomatic montage at 500 Hz tone bursts. Self-monitoring biofeedback was given during the procedure to confirm the tension of the masseter muscle. mVEMPs were recorded across three different plateau duration from 0 to 2 ms with rise/fall time of 2 ms at 95dBnHL. Hence the median and interquartile range were calculated for descriptive analysis of the data followed by non-parametric inferential statistics.

Results Tone burst evoked mVEMPs were found to be 100% present across all three plateau durations for both ears at 95 dBnHL. P11 and N21 latencies increased with longer plateau durations in both ears. There were no significant differences in P11-N21 peak-to-peak amplitude or interaural amplitude ratio (IAAR) observed across different plateau durations. IAAR was lowest for a 2 ms plateau duration in the 2–2-2 cycle. No significant variations were found across the three plateau durations.

Conclusion Significant differences in P11 and N21 latencies were observed across the three stimulus cycles, while no significant differences were found for P11N21 amplitude and IAAR. Yet, there was found to have the highest amplitude and lowest IAAR for 2–2-2 cycle than 2–0-2 and 2–1-2, suggesting it to be the optimal stimulus among the three of them.

Keywords Masseter vestibular evoked myogenic potential, Toneburst, Vestibulo-trigeminal pathway, Masseter muscle

Background

Vestibular-evoked myogenic potentials (VEMPs) are biphasic potentials recorded to assess the functioning of the otolith organs. VEMPs have been recorded from various muscles that include the triceps [1], gastrocnemius [2], neck extensor [3], sternocleidomastoid [4], and inferior oblique [5]. It has also been demonstrated that these short latency myogenic potentials can also be elicited from the masseter muscle [6]. These responses recorded

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from the active masseter muscles while stimulating the vestibular end-organs, are known as masseteric VEMPs (mVEMPs) [6–8].

mVEMPs are inhibitory responses [6] which are relatively less explored as compared to ocular VEMPs (oVEMPs) and cervical VEMPs (cVEMPs). Various stimuli such as tone bursts [9, 10], clicks [7, 11], and chirps [8] have been utilized to evoke these masseteric responses. Two electrode montages, mandibular and zygomatic, are commonly cited in the literature for eliciting these responses [6, 12, 13]. Additionally, ipsilateral mVEMP elicitation is generally preferred over contralateral or bilateral types [14]. In case of the magnitude of masseter muscle tension, there is a reported positive association in elucidating larger mVEMP amplitude [15].

Despite some exploration of factors influencing mVEMP elicitation, parameters such as the optimal plateau duration for eliciting these potentials remain unexplored. In contrast, numerous studies on cVEMPs and oVEMPs have examined stimulus duration for optimal response elicitation [16–18]. Marimuthu et al. [17] documented the effects of P1 and N1 latencies and P1N1 amplitude in cVEMPs with plateau durations exceeding 4 ms. Singh et al. [19] recommended a rise/fall time of 2 ms and a plateau time of 1 ms to evoke robust cVEMP responses. Katner [18] suggested tone burst stimulus of a 2–2–2 cycle for clinical oVEMP elicitation. Takahashi et al. [16] recommended using a 1 ms rise time, 2 ms plateau, and 1 ms fall time tone bursts for optimal cVEMP responses at frequencies between 500 and 750 Hz. However, similar investigations into the stimulus duration for mVEMPs are lacking. Hence, the present study aimed at exploring the optimal plateau duration of toneburst to elicit masseteric vestibular evoked myogenic potentials.

Methods

A within-subjects design was applied in the study. This study was carried out in the hospital setup. This study was approved by Bharati Vidyapeeth (Deemed to be University) Medical College, Institutional Ethics Committee (REF: BVDUMC /IEC/49, date: 7/11/2023). The participants underwent various audio-vestibular tests that include pure tone Audiometry, immittance evaluation, Romberg test, Past pointing test and Fukuda stepping test. All procedures were non-invasive and adhered to the ethical principles outlined in the Declaration of Helsinki (1975).

Participants

The present study determined a total sample size of 30 individuals. The calculation considered a standardized mean difference of 0.184 [19], an effect size of 0.5, a type I error probability of 0.05, and a test power of 0.80. Hence, thirty young healthy adults comprising 15 males and 15 females in the age range 20–30 years ($\bar{x} = 26.50$, $\sigma = 2.13$) with hearing sensitivity ≤ 15 dBHL across 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz octave frequencies participated in the study. All participants had ≥ 100 dB HL of uncomfortable loudness level. Each participant had 'A' type tympanogram with ipsilateral and contralateral reflexes present at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. These individuals were found to have negative response in subjective vestibular screening tests which included Romberg test, Past pointing test and Fukuda stepping test. None of the participants had any history of jaw defects, braces, root canal, ear anomalies, otorrhea, otalgia, itching sensation, fullness of ear or any history of ear related surgery.

Instrumentation

The calibrated Inventis Piano audiometer with RadioEar B-71 bone vibrator and TDH-39 headphones was utilized to assess the hearing thresholds. Interacoustics AT-235 was used to perform immittance evaluation. Furthermore, Intelligent Hearing Systems (Duet) SmartEP software version 5.54.10 along with ER-3A insert earphone was used to generate mVEMP responses.

Procedure

All behavioral and electrophysiological test procedures were conducted in a well-lit, soundproof room that met noise standards (ANSI S3.1, 1999). Skin preparation for electrode placement was performed using Nuprep Skin Prep Gel to elicit mVEMP responses. The zygomatic electrode montage was employed which involved positioning the active electrodes on the zygomatic arch, the reference electrode on the lower third of the masseter muscle, and the ground electrode on the forehead at position Fpz [13], as illustrated in Fig. 1. Therefore, the absolute and inter-electrode impedances was maintained below 5 kΩ and 2 kΩ, respectively.

For recording the responses, tone burst stimuli were presented ipsilaterally across three intensities for each cycle with varying plateau duration, as given in Table 1.

Participants were seated comfortably in an upright position and instructed to clench their jaw to activate the muscles and achieve the required muscle tension. ER-3A insert phones were used to deliver a 500 Hz tone burst to record mVEMP responses. After each recording, participants were given two minutes to relax to avoid fatigue. The specific details about the stimulation and recording settings used to generate mVEMPs has been given in Table 1.

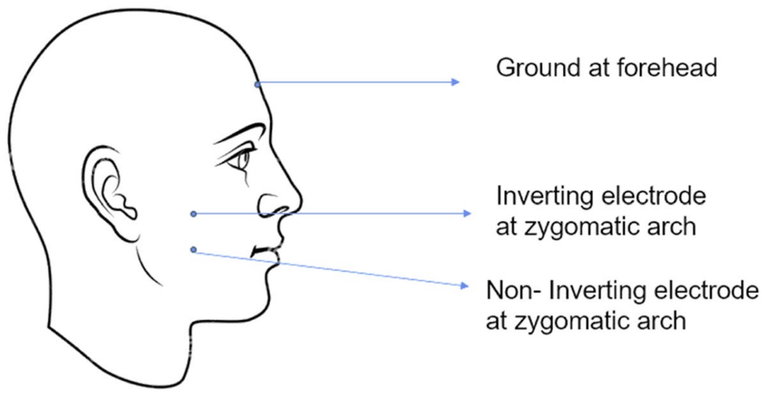

Fig. 1 Representation of the placement for testing the right ear to elicit mVEMP responses

Table 1 Stimulus and acquisition parameters to elicit tone burst-evoked mVEMP responses

	Parameters	mVEMP
Stimulus parameters	Frequency	500 Hz
	Polarity	Rarefaction
	Repetition rate	5.1/s
	Rise-plateau-fall time	2–0-2, 2–1-2, 2–2-2
	Number of sweeps	200
	Transducer	ER-3A insert phone
Recording parameters	Stimulus	Tone Burst 500 Hz
	Filter setting	10–1500 Hz, 6 dB/octave
	Number of channels	Single
	Analysis time	60 ms
	Recording mode	Ipsilateral
	Level of muscle contraction	50 to 150 r.m.s
	Artifact rejection	±800 μV

Data analysis of the recording

The mVEMP responses obtained from each subject were analyzed by two audiologists. The responses were examined to determine the presence or absence of biphasic peaks, peak latencies, peak-to-peak amplitudes, and interaural asymmetry ratio (IAAR). The IAAR was calculated using Jongkee's formula [20].

$$\text{Inter} - \text{aural asymmetry ratio} = 100 * \frac{\text{Better ear P1N1 amplitude} - \text{Poorer ear P1N1 amplitude}}{\text{Better ear P1N1 amplitude} - \text{Poorer ear P1N1 amplitude}}$$

Statistical analysis

Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 29. The Shapiro–Wilk test was used to assess normality, which revealed that the data did not follow a normal distribution ($p < 0.05$). Consequently, the median and interquartile range (IQR) were calculated for mVEMP parameters across cycles with three different plateau durations. Gender-wise comparisons for mVEMP responses were conducted using the Mann–Whitney U test, while ear-wise comparisons were performed using the Wilcoxon signed-rank test. Additionally, the Friedman test was employed to compare parameters across different stimulus cycles with varying plateau durations, followed by post hoc analysis.

Results

Thirty healthy individuals were tested for mVEMP responses across three stimulus cycles with varying plateau durations. This study explored to identify the optimal plateau duration of a 500 Hz toneburst stimulus for eliciting mVEMP responses, considering factors such as response rates, absolute peak latency, P11N21 amplitude, and IAAR. A response rate of 100% was achieved for all three stimulus cycles of the 500 Hz tonebursts in both ears. The characteristics 500 Hz toneburst evoked mVEMP waveforms across the three different cycles (2–0-2, 2–1-2, and 2–2-2) at 95 dBnHL for both ears are illustrated in Fig. 2.

Descriptive statistics were performed to calculate the median and the IQR for the various parameters of mVEMP responses across stimulus cycles with varying plateau durations as illustrated in the box plot given in Table 2.

Table 2 illustrates that the median values of P11 and N21 latencies (msec) tend to increase as the plateau duration extends. On the other hand, the median P11N21 amplitudes lack specific trend as the plateau duration increased for both the right and left ears. Conversely, the IAAR shows a decrease in asymmetry percentage with increasing plateau durations. For inferential statistics,

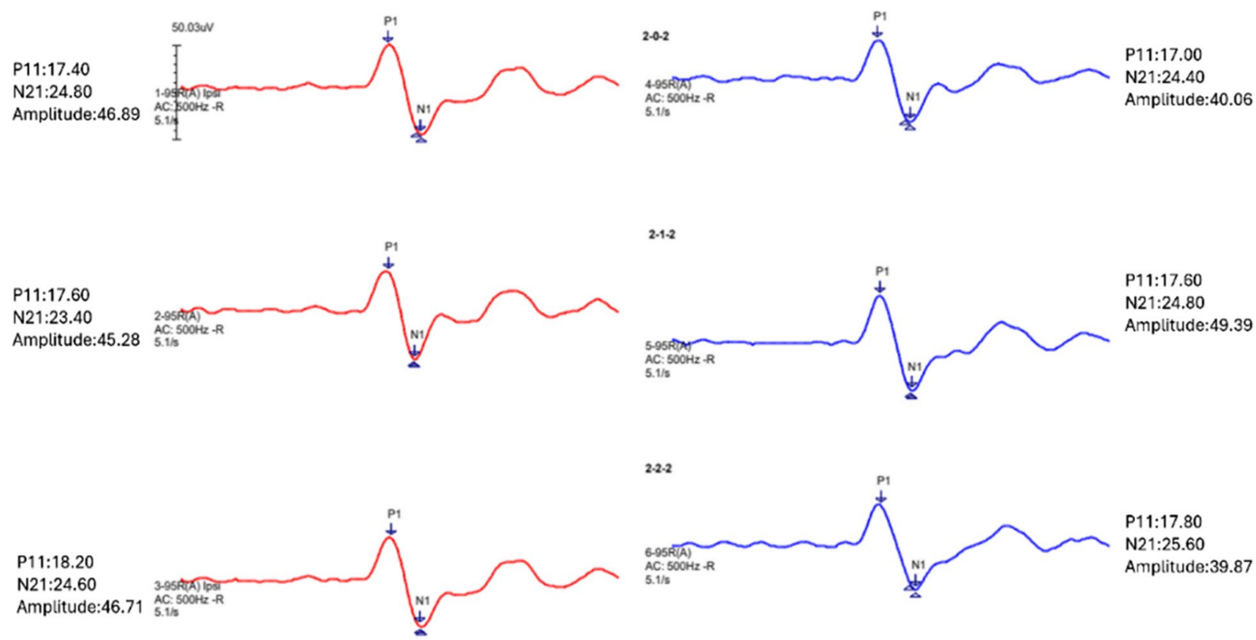

Fig. 2 Representation of mVEMP grand average waveforms of a participant across three different stimulus cycles (2–0-2 cycle, 2–1-2 cycle and 2–2-2 cycle) at 95dBnHL for both ears

Table 2 Descriptive statistics of 500 Hz toneburst evoked mVEMP responses of thirty participants across three different cycles at 95 dBnHL intensity level

Stimulus cycle	Ears	N	Response rate	Descriptive statistics	Latency (msec)		P11N21 amplitude (µV)	IAAR (%)
					P11	N21		
2–0-2	**Right**	**30**	**100%**	**Median**	17.00	23.00	52.50	16.50
				Interquartile Range	16.00–18.00	22.00–24.00	36.00–66.00	7.50–26.25
	Left	**30**	**100%**	**Median**	16.50	24.00	50.00	
				Interquartile Range	16.00–18.00	22.00–25.00	31.00–75.75	
2–1-2	**Right**	**30**	**100%**	**Median**	18.00	23.50	49.50	13.00
				Interquartile Range	17.00–19.00	22.75–25.00	42.75–60.25	6.00–26.00
	Left	**30**	**100%**	**Median**	18.00	24.50	50.00	
				Interquartile Range	17.00–19.00	23.00–25.00	30.00–63.75	
2–2-2	**Right**	**30**	**100%**	**Median**	18.00	24	57.00	8.54
				Interquartile Range	17.00–19.25	24.00–26.00	32.00–74.50	2.00–32.00
	Left	**30**	**100%**	**Median**	18.00	24.00	51.00	
				Interquartile Range	17.00–19.00	23.00–26.25	33.00–76.00	

Friedman test was employed to compare mVEMP responses across cycles with three plateau durations as detailed in Table 3.

Table 3 depicts substantial differences in P11 and N21 latencies for both the right and left ears. However, no significant differences were observed for the P11N21 amplitude and IAAR across different stimulus cycles. Post-hoc analysis using the Wilcoxon signed ranks test revealed a significant difference in median P11 latency between the right and left ears when comparing the 2–0-2 and 2–2-2 cycles, as detailed in Table 4. For N21 latency, substantial differences were noted between the 2–0-2 and 2–2-2 cycles for both ears. Additionally, a significant variation in median values between the 2–1-2 and 2–0-2 cycles was observed only for the right ear.

Discussion

The present research investigated the optimal plateau duration of a 500 Hz toneburst stimulus for eliciting mVEMPs at 95dBnHL in 30 healthy individuals with hearing sensitivity ≤ 15 dBHL. The study utilized three stimulus cycles with varying plateau durations, namely, 2–0-2 cycle, 2–1-2 cycle, and 2–2-2 cycle, corresponding to total stimulus durations of 8 ms, 10 ms and 12 ms respectively. The findings in the study revealed a 100% mVEMP response rate across all three cycles for both ears. Though exploration across different plateau durations have not been previously explored in mVEMP studies, Neupane et al. [8] reported similar mVEMP results using 2–0-2 cycles of toneburst in 25 healthy individuals. Additionally, Arkadi and Neupane [10] reported a 100% mVEMP response rate for 2–2-2 cycles of toneburst in 20 healthy individuals. Analogous findings have been observed in studies of cVEMP and oVEMP as well. Kantner et al. [18] reported a 100% response rate for 500 Hz toneburst evoked cVEMP and oVEMP with plateau durations of 0 ms, 2 ms and 4 ms at 95dBnHL. The achievement of 100% response rates in present study could be due to the fact that all participants were healthy individuals with hearing sensitivity ≤ 15 dBHL and no other health-related comorbidities, indicating robust functioning of the vestibulo-trigeminal pathway.

In this study, the P11 latency and N21 latencies was observed to increase with longer plateau durations of the toneburst for both the right and left ears. Although previous mVEMP studies have not explored latency comparisons across multiple plateau durations, Neupane et al. [8] reported similar latency variations in mVEMP when comparing different stimulus lengths, specifically click, toneburst, and narrowband chirp stimuli. They found that both narrowband chirps along with click stimuli elicited mVEMP responses with significantly shorter P11 latency and N21 latencies compared to tonebursts in both ears. Correspondingly, Marimuthu et al. [17] examined the impact of various plateau times on cVEMPs in 30 healthy adults using 500 Hz toneburst with plateau of 0 ms, 1 ms and 2 ms. Additionally, Singh et al. [19] found that increasing the plateau duration also prolonged P13 and N23 latencies in cVEMP, which is constant with our findings. The present study reported prolonged peak latencies for 2–2-2 cycle followed by 2–1-2 cycle and 2–0-2

Table 3 Friedman test results for parameters of mVEMPs using 500 Hz tone bursts across three different stimulus cycles with varying plateau durations at 95dBnHL

mVEMP parameters	Ear	Test statistics (x^2)	Level of significance (p)
P11 latency	**Right ear**	12.34	< 0.001*
	Left ear	16.79	< 0.001*
N21 latency	**Right ear**	22.17	< 0.001*
	Left ear	6.08	0.045*
P11N21 amplitude	**Right ear**	1.35	0.51
	Left ear	0.86	0.65
IAAR		2.75	0.25

IAAR Interaural asymmetry ratio

*significant difference ($p < 0.05$)

Table 4 Post hoc analysis of 500 Hz tone bursts evoked mVEMP responses across different stimulus cycles using Wilcoxon signed-rank test

mVEMP parameters		2–0-2 vs. 2–1-2		2–0-2 vs. 2–2-2		2–1-2 vs. 2–2-2	
		Z	p	Z	p	Z	p
Right Ear	**P11 Latency**	0.65	0.35	0.70	0.02*	0.05	1.00
	N21 Latency	0.50	1.15	1.15	< 0.001*	0.65	0.04*
Left Ear	**P11 Latency**	0.79	0.07	0.87	0.02*	0.08	1.00
	N21 Latency	0.36	0.58	0.46	0.72	0.21	1.00

Z = test statistic; p = level of significance

*significant difference ($p < 0.05$)

cycle where the plateau have been increasing resulting in total stimulus length of 12 ms, 8 ms, and 10 ms respectively. Longer plateau durations are known to influence the refractory period of vestibular nerve, during which the firing rate slows due to phase shifts between stimulus cycles as the nerve recovers from continuous firing. When the plateau duration exceeds the vestibular nerve's refractory period, the firing rate decreases [21] resulting in delayed latencies, as observed in this study.

Furthermore, the current study revealed no notable differences among P11N21 peak to peak amplitude and IAAR across different plateau. It was found to have the highest mVEMP amplitude at 2–2-2 cycle. Singh et al. [19] found the largest amplitude for a plateau of 0 ms at 2–0-2 cycle. Cheng et al. [22] reported that the ideal plateau of 2 ms with a rise/fall time of 1 ms, noting that amplitude increased up to 5 ms but not at 10 ms. They also reported that a 1 ms plateau had the smallest peak to peak amplitude, with no significant differences among other plateau durations. Takahashi et al. [16] found that tonebursts with plateau times of 2–4 ms elicited the largest oVEMP amplitudes when the rise/fall time was 1 ms; for a rise/fall time of 2 ms, the largest amplitudes were elicited by plateau durations of 0–4 ms. In the current study, the 2–2-2 cycle descriptively showed the highest mVEMP amplitude, followed by the 2–0-2 and 2–1-2 cycles. The amplitude variation could result from differences in firing patterns and synchronicity elicited by these plateau durations. However, the present study lacks the statistical power to determine these differences inferentially.

In the present study, although IAAR was the lowest for a plateau duration of 2 ms in the 2–2-2 cycle, there were no significant variations across the three plateau durations. The results regarding the amplitude asymmetry ratio were consistent with previous studies [8–10, 12]. This study was conducted on healthy individuals with hearing sensitivity $\leq$ 15 dBHL, utilizing visual feedback to maintain constant masseter contraction throughout the procedure. This controlled setting likely contributed to the lack of significant differences across the various plateau durations.

Conclusion

The present study investigated the effect of plateau times on mVEMP using a 500 Hz toneburst, examining parameters such as P11 latency, N21 latency, P11N21 amplitude, and IAAR across three plateau durations (0 ms, 1 ms, and 2 ms). Significant differences in P11 and N21 latencies were observed across the three stimulus cycles, while no significant differences were found for P11N21 amplitude and IAAR. Yet, there was found to have the highest amplitude and lowest IAAR for 2–2-2 cycle than 2–0-2 and 2–1-2, suggesting it to be the optimal stimulus among the three of them.

Limitations and future directions of the study

The present study involved young adults aged 20–40 years, excluding middle-aged and older adults. It utilized limited plateaus with a constant rise/fall time. Hence, future research should include a wider age range and use a greater variety of rise/fall times. Additionally, examining optimal filter settings, polarity, contralateral masking, and gain would be beneficial areas for further study.

Abbreviations

mVEMPs	Masseter vestibular evoked myogenic potentials
IAAR	Interaural amplitude ratio
VEMPs	Vestibular evoked myogenic potentials
oVEMPs	Ocular vestibular evoked myogenic potentials
cVEMPs	Cervical vestibular evoked myogenic potentials
ANSI	American National Standards Institute
SPSS	Statistical Package for the Social Sciences
IQR	Interquartile range

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Authors' contributions

SB conceptualized, developed methods, investigated and curated the data followed by writing the original draft. AKN conceptualized and developed methods, analysed the data, supervised the project and edited the draft.

Funding

None to declare.

Availability of data and materials

All the data generated during the study are contained in this article. Any additional data can be retrieved from the corresponding author, upon reasonable request.

Declarations

Ethics approval and consent to participate

This research protocol received prior ethical approval (reference number BVDUMC /IEC/49) from Bharati Vidyapeeth (Deemed to be University) Medical College, Institutional Ethics Committee on 7th November 2023.

Consent for publication

Informed written consent was obtained from all the participants to participate in the study.

Competing interests

None to declare.

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