Effects of Variation in Response Filter on Ocular Vestibular-Evoked Myogenic Potentials: A Preliminary Investigation

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Abstract

Introduction: The concurrent literature reflects wide variations in the use of response filter for acquiring ocular vestibular-evoked myogenic potentials (oVEMPs). However, there is dearth of published reports on the effects of changes in response filter on oVEMP. Therefore, the present study aimed at evaluating the effect of variations in the response filter on oVEMP and identifying the optimum filter set for its clinical recording. **Methods:** Contralateral oVEMPs were elicited in response to 500 Hz tone bursts from thirty healthy individuals. The low-pass filters used were 500, 700, 1000, 1500, 2000, and 3000 Hz, and the high-pass filters used were 1, 10, and 30 Hz, in all possible combinations. **Results:** There was a significant reduction in n1- and p1-latencies with increase in high-pass and low-pass filters ($P < 0.05$). Further, there was a significant reduction in peak-to-peak amplitude with increasing the high-pass filter ($P < 0.05$) but not for low-pass filters. **Conclusions:** Owing to the finding of the largest amplitude for a 1-Hz high-pass filter and presence of some amount of energy up to 1000 Hz in the power spectrum, 1–1000 Hz appears to be the optimum filter setting for clinical recording of oVEMP.

Keywords: Ocular vestibular-evoked myogenic potential, response filter, tone burst, utricle

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Introduction

Vestibular-evoked myogenic potentials (VEMPs) are otolith-initiated muscle responses elicited by acoustic,[1-3] vibratory,[4,5] or galvanic stimuli.[6] Extraocular muscles, especially the inferior oblique and the inferior rectus, are among several muscles of the human body that have been associated with the recording of VEMPs.[7] When recorded from the extraocular muscles, the VEMP response has been found to show a negative peak with an average latency of about 10 ms (n1 or n10) and a positive peak with a mean latency of almost 15 ms (p1 or p15).[8] This biphasic potential is referred as ocular VEMP (oVEMP).[9-11]

There has been a sudden surge in the studies on oVEMP ever since its first reports in the early 2000s by Todd *et.al*.[8,10] However, there is wide variation in the stimulus and recording parameters used across the studies, even when obtained from individuals with normal audiovestibular systems. One such parameter is the response filter. While most of the studies have used a low-pass filter of 1000 Hz and high-pass filter of 1 Hz,[2,12-14] some of the others have used band-pass filter of 5–500 Hz,[11] 0.5–500 Hz,[15] 10–750 Hz,[16] and 20–2000 Hz.[17] This shows a lack of uniformity in the use of low-pass filter as well as high-pass filter in literature. Although a large range of filter settings have been used, there is lack of experimental evidence to suggest one of these as optimum filter setting for eliciting air-conduction tone burst-evoked oVEMP.

Recently, Wang *et al.*[18] recorded oVEMP from 12 individuals with normal auditory and vestibular system using band-pass filters of 1–1000 Hz, 10–1000 Hz and 100–1000 Hz, 1–500 Hz,

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and 1–2000 Hz. They observed that the peak-to-peak amplitude for a band-pass filter of 1–1000 Hz was significantly larger than that for 10–1000 Hz and 100–1000 Hz. However, there was no significant difference in any of the oVEMP parameters between 1–1000 Hz, 1–500 Hz, and 1–2000 Hz. They concluded that 1–1000 Hz is optimum for recording oVEMP. However, there is no clear information in support of 1–1000 Hz band-pass filter as optimum. Further, the number of participants used in the study was also small and therefore warrants more investigations to confirm the findings to enable generalization of the results to clinical recording of oVEMP. Hence, the present study aimed to identify the optimum response filter setting for acquisition of oVEMP using a larger sample size than the previously reported study by Wang *et al*.[18]

Methods

Participants

The study incorporated thirty ears (15 right and 15 left ears) of thirty individuals with normal auditory and vestibular systems in the age range of 18–35 years after obtaining the informed written consents. The normalcy of the auditory system was ensured through normal results on a battery of audiological tests including pure-tone audiometry, immittance evaluation, transient-evoked otoacoustic emissions, and auditory brain stem response. The vestibular well-being of the participants was ensured through normal results on behavioral balance assessment using the Fukuda stepping test, sharpened Romberg test, tandem gait test, and past-pointing test. In addition, a structured case history was obtained from the participants in order to ensure a lack of history of any otological, vestibular, or neurological diseases.

Procedure

Biologic Navigator Pro (version 7.0.0, Natus Medical Incorporated, Pleasanton, USA) auditory-evoked potential unit was used to acquire oVEMP from all the participants. The testing was done in an acoustically treated room with ambient noise levels well within the acceptable levels for audiometric rooms.[19] The stimulus and acquisition parameters described by previous studies were replicated for the acquisition of oVEMP,[2,11,13,20-22] except filter setting. Surface electrodes were placed 1 cm (noninverting electrode) and 3 cm (inverting electrode) below the center of the lower eyelid and the ground electrode at forehead. Single-channel recording was done with electrodes placed on the side contralateral to the stimulus ear. The participants were instructed to elevate their gaze by 30° in the midline in order to bring the inferior oblique muscle nearer to the surface during recording. Alternating polarity 500 Hz tone bursts, ramped using 1-ms rise/fall time and 2-ms plateau time, were delivered through the standard insert earphones ER-3A of the Biologic Navigator Pro evoked potential system at an intensity of 125 dB SPL and using a repetition rate of 5.1 Hz. Two hundred sweeps of electromyographic activity were recorded using an epoch of 64 ms, which included a 10.5 ms prestimulus (baseline) recording. The responses were band-pass filtered using the low-pass cutoff frequencies of 500 Hz, 700 Hz, 1000 Hz, 1500 Hz, 2000 Hz, and 3000 Hz and the high-pass cutoff frequencies of 1 Hz, 10 Hz, and 30 Hz, in all possible combinations to form band-pass filters. The order of band-pass filter use was pseudorandomized in order to avoid order effect. The responses were multiplied by a factor of 30,000.

Statistical analyses

The waveforms were analyzed by two independent experienced audiologists working in the area of vestibular assessment using ocular VEMP. The interjudge agreement was high ($\alpha \geq 0.92$, Cronbach's alpha test) for peak identification. The parameters analyzed were n1-latency, p1-latency, and peak-to-peak amplitude of oVEMP. Two-way repeated measures analysis of variance (two-way repeated measures ANOVA) for low-pass and high-pass filters was used, separately for each oVEMP parameter. The Bonferroni-adjusted multiple comparisons were performed for pairwise comparisons, whenever a significant main effect was obtained on the two-way repeated measures ANOVA.

Results

Ocular VEMPs were recorded from randomly selected 15 right ears and 15 left ears of thirty healthy individuals. The oVEMPs were present in 100% of the ears. The grand-averaged waveforms obtained for each high-pass filter and low-pass filter combination are shown in Figure 1. Table 1 shows the mean and standard deviation of the various oVEMP parameters for various high-pass and low-pass filter combinations.

Table 1: Mean and standard deviation of latency and amplitude measures of ocular vestibular-evoked myogenic potentials for various high-pass and low-pass filter combinations

Low-pass filters (Hz)	High-pass filters (Hz)								
	n1-latency (ms)			p1-latency (ms)			Peak-to-peak amplitude (μV)		
	1	10	30	1	10	30	1	10	30
500	10.68 (0.41)	10.76 (0.51)	10.44 (0.53)	16.32 (0.84)	16.13 (0.79)	15.42 (0.71)	12.22 (7.99)	11.65 (7.81)	10.00 (6.68)
700	10.61 (0.47)	10.58 (0.47)	10.37 (0.36)	16.09 (0.74)	15.95 (0.83)	15.41 (0.70)	11.54 (6.91)	11.28 (7.67)	9.78 (6.42)
1000	10.51 (0.36)	10.49 (0.49)	10.25 (0.37)	16.03 (0.83)	15.93 (0.78)	15.35 (0.91)	11.92 (8.02)	11.62 (7.49)	9.99 (6.58)
1500	10.27 (0.42)	10.37 (0.57)	9.98 (0.37)	15.96 (0.82)	15.79 (0.85)	14.99 (0.73)	11.89 (7.81)	11.79 (7.85)	10.42 (6.47)
2000	10.35 (0.42)	10.34 (0.54)	10.03 (0.40)	15.96 (0.69)	15.79 (0.80)	15.23 (0.75)	12.06 (8.01)	11.64 (8.09)	10.20 (6.35)
3000	10.32 (0.53)	10.13 (0.38)	9.98 (0.34)	15.96 (0.77)	15.64 (0.68)	15.04 (0.90)	12.41 (8.21)	11.61 (8.01)	10.10 (6.15)

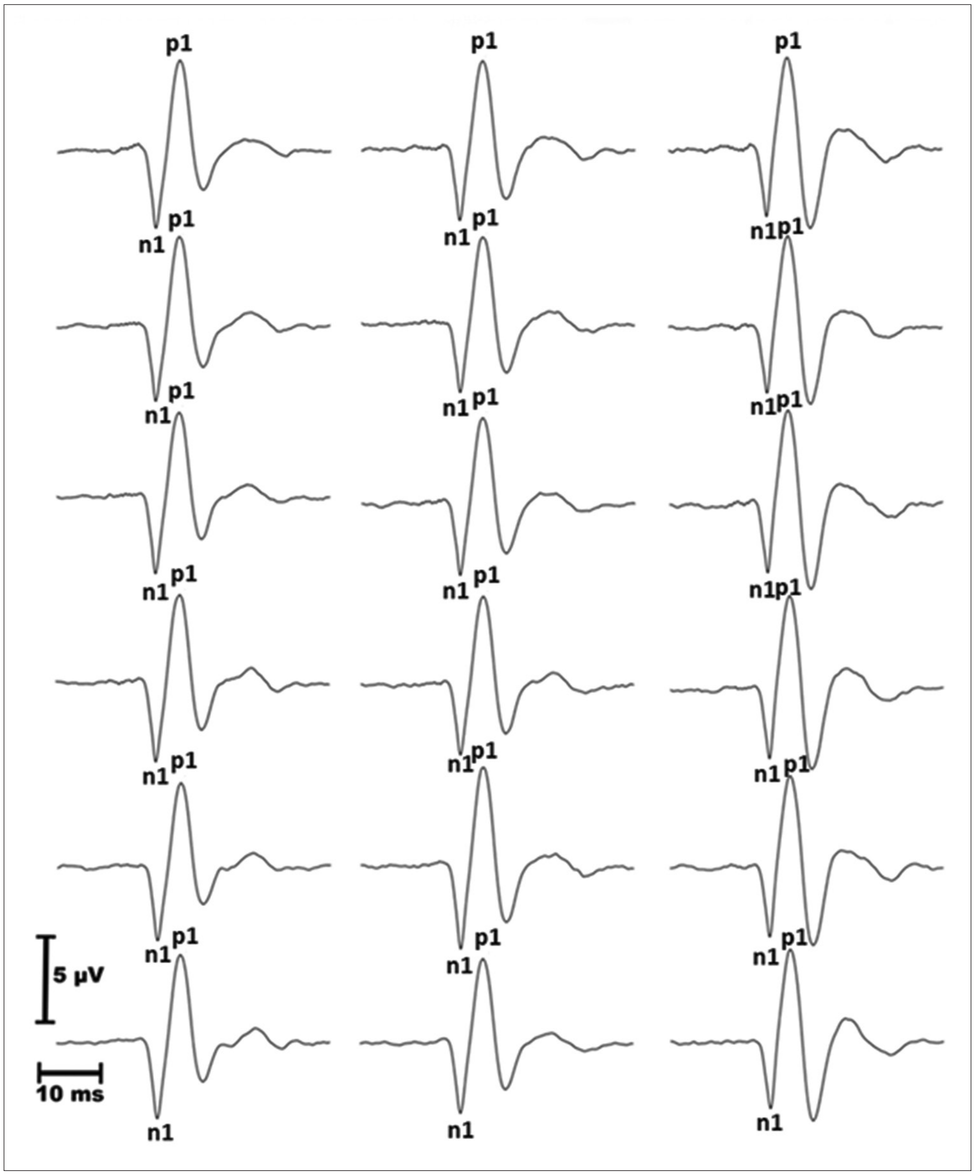

Figure 1: The grand-averaged ocular vestibular-evoked myogenic potential waveforms acquired for various high-pass and low-pass filters from thirty ears. The high-pass filters of 1 Hz, 10 Hz, and 30 Hz are represented in rows from left to right, and low-pass filters of 500 Hz, 700 Hz, 1000 Hz, 1500 Hz, 2000 Hz, and 3000 Hz are depicted in columns from top to bottom. Negativity is plotted in downward direction

For comparison of n1-latencies, a two-way repeated measures ANOVA was done for high-pass and low-pass filters. The results revealed a significant main effect of high-pass filter ($F(2,58) = 22.84$, $P < 0.001$) and low-pass filter ($F(5,145) = 53.50$, $P < 0.001$) on n1-latency of oVEMP. Further, there was no significant interaction between high-pass and low-pass filters ($F(10,290) = 1.64$, $P > 0.05$). The Bonferroni-adjusted multiple comparisons revealed a significant reduction in n1-latencies with increase in high-pass as well as low-pass filters, except a few pairs. Figure 2 shows the mean and 95% confidence intervals of n1-latencies across the low-pass and high-pass filters and the outcome of the Bonferroni-adjusted multiple comparisons between various high-pass filters and low-pass filters. In the high-pass filters, the n1-latency corresponding to 30 Hz was significantly smaller than that for 1 Hz and 10 Hz ($P < 0.05$); however, there was no significant difference between 1 Hz and 10 Hz ($P > 0.05$). As far as the low-pass filters were concerned, the n1-latency for the filters up to 1000 Hz was significantly different from each other as well as the higher frequencies ($P < 0.05$), with an exception of no significant difference between 500 Hz and 700 Hz. The low-pass filters of 1500 Hz, 2000 Hz, and 3000 Hz were significantly not different from each other ($P > 0.05$).

In terms of the p1-peak of oVEMP, there was a significant main effect of high-pass filter ($F(2,58) = 67.54$, $P < 0.001$) and low-pass filter ($F(5,145) = 12.63$, $P < 0.001$) on the latencies but no significant interaction between high-pass and low-pass filters ($F(10,290) = 1.25$, $P > 0.05$). Bonferroni-adjusted multiple comparisons revealed a significant reduction in p1-latency with increase in the high-pass as well as low-pass filter, except few pairs. The p1-latencies corresponding to each of the high-pass filters were significantly different from those of the others ($P < 0.05$). However, the comparison of p1-latency between various low-pass filter pairs revealed significantly longer latencies for 500 Hz and 700 Hz than 1500 Hz, 2000 Hz, and 3000 Hz ($P < 0.05$). None of the remaining pairs of low-pass filters were significantly different from each other ($P > 0.05$). Figure 3 shows mean and 95% confidence intervals of p1-latency across the high-pass and low-pass filters and the outcome of the Bonferroni-adjusted multiple comparisons between various high-pass filters and low-pass filters.

A two-way repeated measures ANOVA was done to evaluate the effect of different high-pass and low-pass filters on peak-to-peak amplitude of oVEMP. The results revealed a significant main effect of high-pass filter on peak-to-peak amplitude of oVEMP ($F(2,58) = 17.51$, $P < 0.001$). However, there was no significant main effect of low-pass filter on peak-to-peak amplitude of oVEMP ($F(5,145) = 1.56$, $P > 0.05$). Further, there was no significant interaction between high-pass and low-pass filters ($F(10,290) = 0.34$, $P > 0.05$). Bonferroni-adjusted multiple comparisons revealed significantly lower peak-to-peak amplitude of oVEMP for 30 Hz when compared to 1 Hz and 10 Hz ($P < 0.05$). However, there was no significant difference between 1 Hz and 10 Hz ($P > 0.05$). Figure 4 shows mean and 95% confidence intervals of peak-to-peak amplitude across the high-pass and low-pass filters and the outcome of the Bonferroni-adjusted multiple comparisons between various high-pass filters.

Power spectrum

The power spectrum analysis was done to investigate the energy content in the oVEMP response waveforms across the frequencies. For this, a MATLAB program was used. Figure 5 shows the power spectrum of all the waveforms recorded during the present study, irrespective of the band-pass filters.

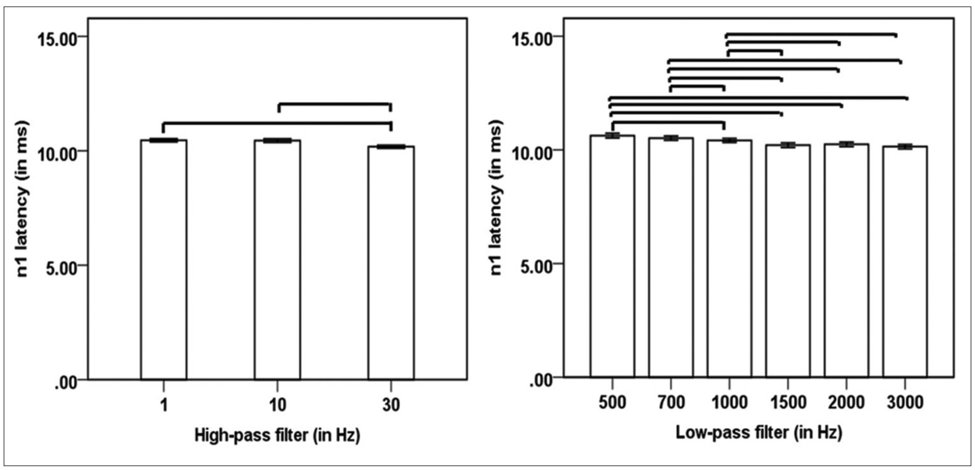

Figure 2: Mean and 95% confidence intervals of n1-latency of ocular vestibular-evoked myogenic potential and the outcome of Bonferroni-adjusted multiple comparisons between various low-pass filters (right panel) and also between various high-pass filters (left panel). The horizontal bars represent significant difference between the pairs ($P < 0.05$)

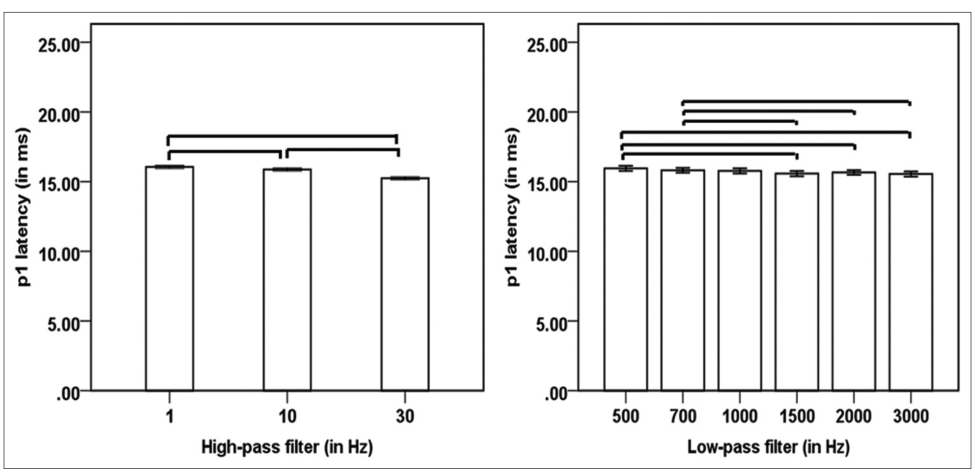

Figure 3: Mean and 95% confidence intervals of p1-latency of ocular vestibular-evoked myogenic potential and the outcome of Bonferroni-adjusted multiple comparisons between various low-pass filters (right panel) and also between various high-pass filters (left panel). The horizontal bars represent significant difference between the pairs ($P < 0.05$)

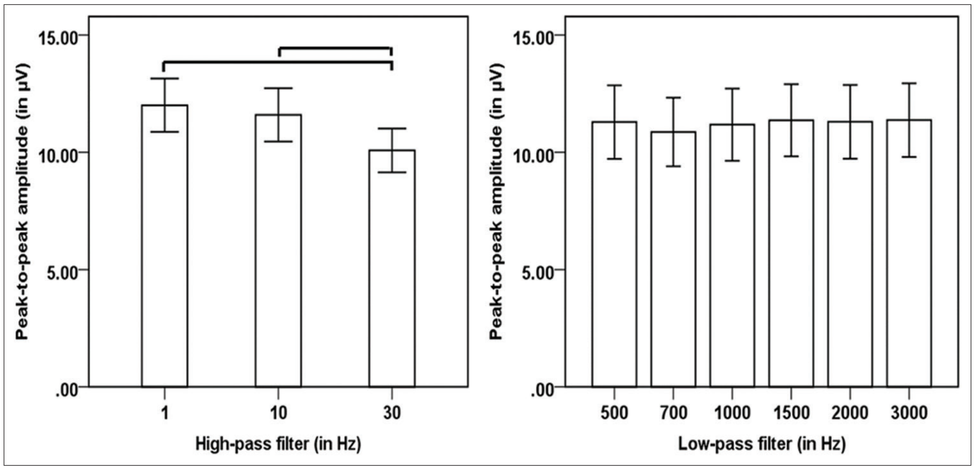

Figure 4: Mean and 95% confidence intervals of peak-to-peak amplitude of ocular vestibular-evoked myogenic potential and the outcome of Bonferroni-adjusted multiple comparisons between various low-pass filters (right panel) and also between various high-pass filters (left panel). The horizontal bars represent significant difference between the pairs ($P < 0.05$)

The major energy was observed up to 500 Hz with the peak at around 100 Hz. There was no energy beyond 1000 Hz.

Discussion

The responses were present in all the thirty individuals irrespective of the band-pass filter being used which meant that the response rate was 100%. This is in slight disagreement with the findings of a previous study in this regard.[18] For a constant low-pass filter of 1000 Hz, they demonstrated significant reduction in response rate when the high-pass filter for recording oVEMP was changed to 100 Hz from 1 Hz or 10 Hz.[18] However, Wang *et al*.[18] did not observe a difference for any of the other band-pass filters (1–500, 1–1000, and 10–1000 Hz) which was similar to the findings of the present study. They suggested that the significant reduction in the response rate for this particular band-pass filter (100–1000 Hz) when compared to the other band-pass filters (1–1000 Hz and 10–1000 Hz) was because of the attenuation of significant amount of energy in the low-frequency region. Reduction in energy in these areas would have caused much smaller waveforms and probably the absence of some of the already small amplitude waveforms. In the present study also, the major energy concentration was at around 100 Hz; however, the highest high-pass filter used was 30 Hz. This probably was not sufficient to completely eliminate the identification of responses in any individual, thereby causing a 100% response rate irrespective of the band-pass filter.

The results of the present study showed a significant gradual shortening of latencies with increase high-pass as well as low-pass filter of the band-pass filter used for recording oVEMP. Although Wang *et al*.[18] observed a similar trend of reduction in latencies with increasing the low-pass and high-pass filters, the difference was significant only when the high-pass filter was increased from 1 to 100 Hz. The reason behind reduction in the latencies with increasing the low-pass

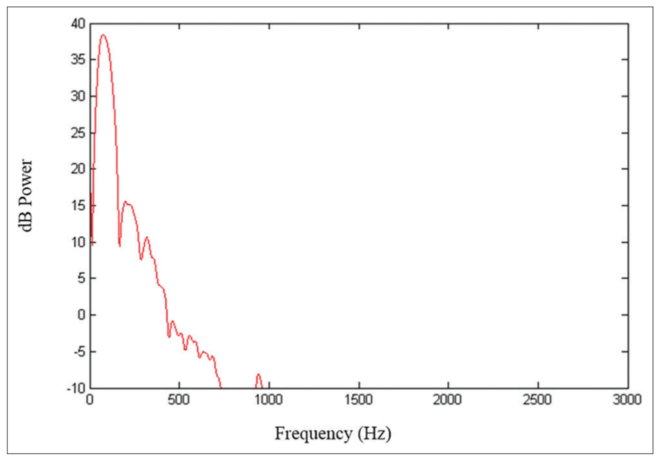

Figure 5: The power spectrum of the grand-averaged ocular vestibular-evoked myogenic potential response waveform which was obtained by ignoring the differences in the band-pass filters

and high-pass filters could be the phase distortion that is introduced by the use of narrow filters like the one used in the present study. Similar effects of changing the filter setting have been observed for other tone burst-evoked auditory-evoked potentials such as auditory brain stem responses.[23]

In terms of the peak-to-peak amplitude, the results of the present study revealed reduction in amplitude with increase in high-pass filter but not low-pass filter. This is again similar to the findings of Wang *et al*.[18] These findings could be attributed to the frequency composition of oVEMP response which revealed only a small amount of energy between 500 Hz and 1000 Hz and almost no energy above 1000 Hz. Increasing the low-pass filter cutoff to 1000 Hz will, therefore, not only ensure acceptable frequency width but also reduce the contamination from background noise. Further, the use of high-pass filter of 1 Hz will ensure large amplitude which will ensure its detection in older individuals with reduced muscle tone in whom the oVEMP amplitude is inherently small.[24] Therefore, the band-pass filter of 1–1000 Hz appears to be the optimum filter setting for recording oVEMP clinically.

Conclusion

The latencies of both peaks reduced significantly as the high-pass and low-pass filters increased. In terms of the peak-to-peak amplitude, increase of high-pass filter caused significant reduction of amplitude; however, no such change was observed for increasing the low-pass filter. The largest peak-to-peak amplitude was coincident with the use of 1-Hz high-pass filter and there were evidences for some amount of energy up to 1000 Hz in the power spectrum, leading us to conclude that 1-1000 Hz is the optimum filter setting for clinical recording of oVEMP.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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