Annals of Medical Research
DOI: 10.5455/annalsmedres.2019.11.693 2020;27(3):819-24

Original Article

Is chirp more effective than click and tone-burst during oVEMP test?

Banu Bas[1], Kemal Keseroglu[2], Serap Er[2], Ali Ozdek[3], Mehmet Hakan Korkmaz[2]

[1]Yildirim Beyazit University, Faculty of Health Science, Department of Audiology, Ankara, Turkey
[2]Diskapi Yildirim Beyazit Training and Research Hospital, Clinic of Otolaryngology, Ankara,Turkey
[3]Private ENT Clinic, Ankara, Turkey

Abstract

Aim: We aimed to show the effectivity of chirp stimulus and to compare with tone-burst and click stimulus during ocular VEMP (oVEMP) and also to exhibit same stimulation response pattern in utricle as seen in cochlea.

Material and Methods: A total of 85 healthy volunteers without any vestibular and otologic disease history were enrolled in this study. Three different types of air conduction stimuli (tone-burst, click and chirp) were used for the oVEMP test. N1, P1 latencies, N1P1 amplitudes and asymmetry ratios were investigated for each stimulus type according to age subgroups and sex.

Results: The ratio of presence of oVEMP response was found to be 94.1%, 82.1% and 98.8% with tone-burst, click and chirp stimuli respectively. The latencies were significantly shorter in chirp stimulus with respect to others in both ears. The amplitudes were also significantly larger in chirp stimulus with respect to other in both ears. According to analysis of N1P1 asymmetry ratios, N1 and P1 latency asymmetry, there were no statistically significant difference in these values within each stimulus types.

Conclusion: oVEMP is more practical, easier, faster and less invasive method. oVEMP results with chirp stimulus have shorter latency and higher amplitude and more clear waveform morphology with higher ratio of response when compared to click and tone-burst stimulus. As a result, chirp is a reliable and suitable stimulus type for oVEMP analysis. In the light of these unique results with chirp stimulus, utricular hair cells may have similar frequency specific tonotopic organization as seen in cochlea.

Keywords: oVEMP; chirp; click; tone-burst

INTRODUCTION

Ocular vestibular evoked myogenic potentials (oVEMP) are myogenic response to air, bone and galvanic stimulus via vestibuloocular reflex pathway to examine the utricular function (1). This short latency response is a crossed excitatory reflex of the extraocular muscles (EOM) (2). It has been applied in the clinical diagnosis of peripheral vestibular disorders especially in vestibular neuritis, superior canal dehiscence and Meniere's disease since Rosengren et al. first described the recording of myogenic potentials from EOM via bone-conducted stimulus (BCS) in 2005 (3). After the introduction of myogenic potentials from contralateral EOM with air-conducted stimulus (ACS) by Todd et al. in 2007, this test has become more popular in the vestibular laboratories (4,5).

Although oVEMP is an objective test battery, there are some factors affecting the results. The existence and the morphology of the wave are the main outcomes for the clinical interpretation. In addition to the stimulus type, frequency, intensity and duration, phase difference; recording parameters, location and impedance of the surface electrodes, degree of the upward gaze are the variable factors affecting the waveform morphology (6-9). Furthermore, age, gender and hearing status of the patient should be taken into consideration (5,10,11).

The chirp stimulus is a frequency and time modulated type of a ACS which has been designed for the compensation of the time delay to increase the temporal synchrony in the cochlea during auditory brain response(ABR) test (12,13). Broad-band and band-limited chirp stimuli are

Received: 04.11.2019 **Accepted:** 17.12.2019 **Available online:** 10.03.2020
Corresponding Author: Banu Bas, Yildirim Beyazit University, Faculty of Health Science, Department of Audiology, Ankara, Turkey
E-mail: fzt_banu@hotmail.com

the main types with respect to frequency spectrum and time domain (12). Until now, there are only 3 studies with chirp stimulus in cVEMP in the literature and there is only 1 study about oVEMP in which band-limited chirp stimulus was used in normal volunteers (n: 9) and patients with vestibular neuritis (n:6)(14-16). Furthermore, there is no such a study with wide-band chirp stimulus in oVEMP analysis in the healthy subjects.

The aim of this study was to determine the normal characteristics of the wide-band chirp stimulus and to compare with click and 500 Hz tone-burst stimulus in an age stratified group of healthy individuals in the oVEMP test.

MATERIAL and METHODS

This prospective study was performed with 85 healthy participants in a tertiary referral center. All participants signed the informed consent and local ethics committee approved the protocol before starting the study (03.2016, 27/06).The study group consisted of healthy people with normal hearing level and otoscopic examination. The individuals who were < 18 and >60 years old, with any history of vestibular disorder, hearing loss, pathology in the otoscopic examination and absence of response at least one side of ear in any type of stimulus during oVEMP test were excluded from the study. The audiologic examination consisted of pure tone audiogram and tympanometry. Pure tone thresholds lesser than 15 dB within 500, 1000, 2000, 4000 Hz frequencies and type A 226 Hz tympanometry results were accepted as normal hearing.

oVEMP Technique

All the individuals were evaluated with the oVEMP device (Neurosoft®, Neuro-Audio.NET model, Ivanovo, Russia) and ER-3A insert earphone. The test was performed monoaurally in supine position with upwards gaze of 30 degrees in vertical plane to a fixed target point. After cleaning the electrode places with peeling gel, self-adhesive active electrodes (Ambu® Neuroline 720, Denmark) were placed to infraorbital rim at the level of cornea and the reference electrode was put 1 cm below the active electrode bilaterally. The ground electrode was placed to the center of forehead. The test results with the impedance of the electrodes under 5000 ohm were analyzed.

For the standardization, monoaural short tone-burst (Blackman window, rise/fall time: 2 ms and plate time: 0 ms), click (0.1 ms) and wide-band chirp (10-10000 Hz, 4 ms) air conducted stimuli with 105 dB nHL (rarefaction polarity, 1-1000 Hz band-pass filtered) were applied in a randomized order with 5 minutes of resting time to eliminate the EOM fatigue. The analysis time was 50 ms and the stimulation rate was 5Hz with a maximum of 120 stimuli count. Two consecutive clear waves were averaged for the analysis. The latency of N1, P1 (ms), interpeak amplitude of P1N1(uV) and P1N1 interaural asymmetry (%) were analyzed.

Statistical Analysis

The statistical analysis was performed with the software IBM SPSS statistics 21.0. The continuous variables were expressed as mean ± standard deviation, and categorical variables were expressed as counts (percentages). For comparison of the independent groups, Variance Analysis and Independent Samples t Test when parametric test assumptions were provided; Kruskal Wallis Variance Analysis and Mann-Whitney U test were used when parametric test assumptions were not provided. For comparison of the dependent groups, Repeated Measures Anova and Paired samples t Test was used when parametric test assumptions were provided; Friedman Test and Wilcoxon Signed Rank Test was used when parametric test assumptions were not provided. Chi-Square test was used for assessing the difference between categorical variables.

RESULTS

Among the 85 subjects, the percentage of bilateral positive response were 94.1% (n: 80), 82.3% (n: 70) and 98.8% (n: 84) within tone-burst, click and chirp stimuli respectively. The statistical analysis was performed in 66 individuals who had bilateral positive response with each stimuli. There were 45 (68.2%) female and 21 (31.8%) male subjects with a mean age of 36.89 +/- 11.37. The study group was divided into subgroups with respect to age as 19-29 (n:21), 30-39 (n:15), 40-49 (n:15) and 50-59 (n:15).

Latency Analysis

N1 and P1 latencies were analyzed with each stimulus in each age subgroups. The latencies of N1 and P1 with chirp stimulus were significantly shorter than the latencies of click and tone-burst bilaterally (p: 0.0001). Chirp stimulus latencies didn't show any significant variability among the age subgroups as similarly in tone-burst and click stimuli. The only significant variability was between 19-29 and 40-49 subgroups on the right ear P1 latencies with chirp stimulus. (p: 0.046) (Table 1).

P1N1 Amplitude Analysis

There were statistically significant larger P1N1 amplitudes with chirp compared to click and tone-burst in all age subgroups (Table 2). However, there were no statistically significant difference in bilateral P1N1 amplitudes of the tone-burst within all age subgroups, there were statistically significant lower amplitudes in 40-49 group with respect to 19-29 group in the right ear chirp and click group and in the left ear chirp group (Table 2).

P1N1 Interaural Asymmetry Analysis

P1N1 interaural asymmetry was used to evaluate the P1N1 amplitudes on both ears. There was no statistically significant difference with all stimuli types within all age subgroups (Table 3).

Table 1. The oVEMP latencies of each ear according to tone-burst, click, and chirp stimuli within age subgroups

Side	Latency	Stimulus Type	Age Subgroups				p value (β)
			19-29	30-39	40-49	50-59	
Right	N1(ms)	Tone-Burst	9.69 ± 0.41	10.06 ± 0.86	10.05 ± 0.88	10.38 ± 1.19	0.384
		Click	8.23 ± 1.03	8.38 ± 1.41	9.11 ± 1.74	9.11 ± 1.54	0.254
		Chirp	5.71 ± 0.33	5.79 ± 1	6.03 ± 0.76	6.17 ± 1.37	0.365
	p value(γ)		0.0001*	0.0001*	0.0001*	0.0001*	
Left	N1 (ms)	Tone-Burst	9.72 ± 0.39	10 ± 0.59	10.47 ± 1.24	10.28 ± 1.04	0.128
		Click	8.4 ± 1.3	8.31 ± 1.33	8.87 ± 1.78	9.03 ± 1.51	0.615
		Chirp	5.72 ± 0.49	5.79 ± 0.62	6.59 ± 1.53	6.13 ± 1.22	0.23
	p value(γ)		0.0001*	0.0001*	0.0001*	0.0001*	
Right	P1 (ms)	Tone-Burst	14.73 ± 1	14.97 ± 1.12	14.87 ± 1.24	15.05 ± 1.58	0.637
		Click	13.12 ± 1.24	12.64 ± 2.2	12.35 ± 2.16	12.67 ± 1.71	0.649
		Chirp	10.92 ± 0.55	10.89 ± 0.83	11.33 ± 0.86	11.17 ± 1.38	0.196
	p value(γ)		0.0001*	0.0001*	0.0001*	0.0001*	
Left	P1(ms)	Tone-Burst	14.98 ± 0.87	14.96 ± 0.91	15.3 ± 1.84	15.17 ± 1	0.872
		Click	13.02 ± 1.23	12.51 ± 2.29	12.43 ± 2.49	12.63 ± 1.46	0.959
		Chirp	10.83 ± 0.62	11.11 ± 0.87	11.84 ± 1.28	11.62 ± 1.27	0.046*
	p value(γ)		0.0001*	0.0001*	0.0001*	0.0001*	

Mean±SD; median (min-max), (γ: Friedman Test, β: Kruskal Wallis Variance Analysis Test, *: p<0.0001)

Table 2. The oVEMP P1N1 amplitudes of each ear according to tone-burst, click, and chirp stimuli within age subgroups.

Side		Stimulus Type	Age Subgroups				p value (β)
			19-29	30-39	40-49	50-59	
Right	P1N1 amplitude (uV)	Tone-Burst	8.2 ± 5.48	6.75 ± 3.26	5.07 ± 1.,42	7.92 ± 7.3	0.377
		Click	3.72 ± 2.88	2.91 ± 1.98	1.95 ± 0.75	2.14 ± 0.77	0.027*
		Chirp	13.43 ± 7.15	9.09 ± 4.16	7.48 ± 3.5	10.88 ± 10.65	0.015*
	p value(γ)		0.0001*	0.0001*	0.0001*	0.0001*	
Left	P1N1amplitude (uV)	Tone-Burst	8.63 ± 3.2	7.84 ± 3.42	6.06 ± 2.82	7 ± 4.24	0.138
		Click	3.8 ± 2.76	2.67 ± 1.33	2.03 ± 1.12	2.57 ± 1.15	0.052
		Chirp	14.96 ± 8.49	11.62 ± 5.78	8.06 ± 3.83	11.85 ± 8.27	0.027*
	p value(γ)		0.0001*	0.0001*	0.0001*	0.0001*	

Mean±SD; median (min-max), (γ: Friedman test, β: Kruskal Wallis Variance Analysis Test, *: p<0.0001)

Table 3. The oVEMP interaural asymmetry according to tone-burst, click and chirp stimuli within age subgroups

	Stimulus Type	Age Subgroups				p value (β)
		19-29	30-39	40-49	50-59	
Interaural Asymmetry(%)	Tone-Burst	20.28 ± 16.12	13.45 ± 12.16	21.92 ± 11.65	18.81 ± 11.58	0.281
	Click	19.87 ± 14.96	16.69 ± 12.01	16 ± 11.81	17.58 ± 8.6	0.343
	Chirp	17.7 ± 12.27	19.25 ± 11.72	19.01 ± 13.95	18.5 ± 13.85	0.051
p value(γ)		0.721	0.419	0.383	0.936	

Mean±SD; median (min-max),(α: Variance Analysis and Independent Samples t Test, δ: Anova test)

Table 4. The oVEMP parameters according to gender with tone-burst, click, and chirp stimuli

Side	oVEMP Value	Stimulus Type	Sex		p value (β)
			Female	Male	
Right	N1(ms)	Tone-Burst	10.02 ± 0.92	10 ± 0.74	0.772
		Click	8.63 ± 1.3	8.74 ± 1.74	0.72
		Chirp	6 ± 0.96	5.69 ± 0.74	0.156
		p value(γ)	0.0001*	0.0001*	
	P1(ms)	Tone-Burst	14.88 ± 1.23	14.9 ± 1.2	0.634
		Click	12.65 ± 1.7	12.91 ± 2.03	0.47
		Chirp	11.12 ± 1.03	10.95 ± 0,63	0.228
		p value(γ)	0.0001*	0.0001*	
	P1N1 Amplitude (uV)	Tone-Burst	7.18 ± 5.31	6.91 ± 4.37	0.675
		Click	2.94 ± 2.37	2.42 ± 1.04	0.934
		Chirp	10.4 ± 7.99	10.76 ± 5.32	0.363
		p value(γ)	0.0001*	0.0001*	
Left	N1(ms)	Tone-Burst	10.05 ± 0.99	10.15 ± 0.57	0.082
		Click	8.62 ± 1.51	8.64 ± 1.43	0.521
		Chirp	6.19 ± 1.17	5.69 ± 0.64	0.044*
		p value(γ)	0.0001*	0.0001*	
	P1(ms)	Tone-Burst	15.04 ± 129	15.19 ± 0.89	0.642
		Click	12.54 ± 1.88	12.98 ± 1.81	0.625
		Chirp	11.4 ± 1.04	11.09 ± 1.13	0.11
		p value(γ)	0.0001*	0.0001*	
	P1N1 Amplitude (uV)	Tone-Burst	7.24 ± 3.49	8.05 ± 3.53	0.382
		Click	3.06 ± 2.25	2.43 ± 0.88	0.338
		Chirp	11.94 ± 7.89	11.9 ± 6.13	0.596
		p value(γ)	0.0001*	0.0001*	
	P1N1 Interaural Asymmetry (%)	Tone-Burst	16.97 ± 11.31	22.6 ± 16.71	0.228
		Click	17.36 ± 12.87	18.58 ± 10.8	0.54
		Chirp	17.69 ± 12.13	20.34 ± 13.79	0.509
		p value(γ)	0.954	0.521	

Mean±SD; median (min-max),(γ: Friedman test λ: Mann Whitney U test, *: p<0,0001)

Gender Analysis According to Stimulus Types

N1, P1 latencies and P1N1 amplitudes were analyzed according to gender with each stimuli bilaterally. N1 and P1 latencies were statistically significantly shorter than tone-burst and click stimuli on each ears and P1N1 amplitude was statistically significantly larger on both ears in male and female subjects. P1 and N1 latencies, P1N1 amplitude and P1N1 interaural asymmetry had no statistically significant difference between male and female group except left N1 latency with chirp stimulus, shown in table 4. There was a statistically shorter N1 latency on left ear in male patients with respect to female group which was not seen in other stimulus types (Table 4).

DISCUSSION

The peripheral vestibular system consists of semicircular canals and otolithic organs in utricle and saccule which sense the rotational and linear acceleration of the head respectively (7). The head impulse test, caloric test and VEMP are the main tools used for the evaluation and differential diagnosis of the specific location and side of disorder in the vestibular periphery (17,18). However, the otolithic organs are sensitive to linear movement of the head, it has been found that some afferents from irregular otolithic neurons in the striolar region respond to BCS and ACS (7,19,20).By the help of these stimulus sensitive neurons, vestibulocollic reflex via cVEMP and vestibulocular reflex via oVEMP can be easily evaluated (7). In order to perform further evaluation in vestibular disorders, it is important to know the normal characteristics of the oVEMP test in normal healthy individuals. Therefore, we aimed to demonstrate the characteristics of the response of these neurons via oVEMP with wide-band chirp stimulus and to compare with click and 500 Hz tone-burst stimuli.

In the oVEMP analysis, the first interpretation should be the response rate of the stimulus. In the present study, chirp response rate (98.8%) was higher than click (82.3%) and tone-burst (94.1%). In the literature, the response rate range of oVEMP was found to be 75-100% with different types of stimulus which is comparable with chirp response rate in our study (10,21,22). Age is one of the factors influencing the response rate (5,6,23). There is a clear evidence in the literature that response rates are often reduced in the population over 60 years of age (5,6,21,24). Moreover, peripheral vestibular disorders are more commonly encountered in adults with respect to pediatric group (25). Thus, patients with <18 and > 60 years of age were excluded in this study.

Secondly, the evaluation of the waveform morphology alterations such as N1, P1 latencies, P1N1 amplitudes and interaural asymmetry is more challenging with respect to response rate especially in the pathologic disorders of the vestibular system. In this study, N1 and P1 latencies with chirp stimulus were significantly shorter in all age groups bilaterally compared to click and 500 Hz tone-burst stimuli. In Walther's study (n:9), the latencies of chirp and 500 Hz tone-burst were not significantly different whereas click latency was significantly shorter than chirp and tone-burst (16). On the other hand, in the studies of Wang et al. (n:30) and Özgür et al.(n:39) with cVEMP, latencies were significantly shorter with chirp stimulus(14,15). Due to tonotopicly organized structure of the cochlea and travelling wave theory of von Bekesy, chirp stimulus can compensate the time delay in ABR test due to property of frequency and time modulation (26). However, this special type of organization is unclear in the otolytic organs. Curthoys et al. explained it with the fluid pressure wave hypothesis (19) .There is only one study with an evidence of goldfish saccule tonotopic organization (27). Shorter latencies with chirp can be explained with similar tonotopic organization of the irregular neurons in the utricle as seen in cochlea.

P1N1 amplitudes with chirp stimulus were significantly greater than click and 500 Hz tone-burst stimuli in all age groups. In the studies of Walther et al. and Wang et al., higher amplitudes were obtained in both cVEMP and oVEMP with respect to other types of stimuli (14,16). Whereas Özgür et al. found that lowest amplitudes were achieved with chirp stimulus (15). In ABR test, chirp stimulus causes synchronous neural output in the cochlea which result in greater amplitude of the electrical potential waves originating from the cochlear nerve and brainstem (13,26). Similarly, we found that chirp stimulus resulted in greater amplitudes in oVEMP. Though myogenic potentials are not analogous with electrical response in ABR, chirp stimulus may induce much more stimulation of the irregular afferent neurons in the utricle which consequently result in greater myogenic potential in the EOM via superior vestibular nerve.

Interaural asymmetry is the other parameter of waveform morphology for the comparison of each ear especially in the unilateral peripheral vestibular pathologies. The latency or amplitude data can be compared with contralateral findings. We preferred to compare the amplitude values and there was no significant difference in P1N1 amplitude interaural asymmetry of chirp stimulus with respect to click and 500 Hz tone-burst. Moreover, interaural asymmetry of chirp didn't change significantly according to age subgroups. Özgür et al. and Wang et al. also found similar results regarding asymmetry ratios of chirp with respect to click and tone burst in cVEMP (14,15).

Even though left ear N1 latency was significantly shorter in male group, in the terms of other parameters of both sides, there was no significantly difference in gender analysis with respect to any stimulus type. There is a conflicting data about sex and VEMP results in the literature (5,28). This study showed that gender difference did not influence the oVEMP results.

CONCLUSION

Although VEMP is more practical, easier, faster and less invasive method with respect to caloric test to evaluate the peripheral vestibular system, the interpretation of the results has some attentive features. First of all, normative values of age matched healthy subjects are necessary for the evaluation of pathologic results. Secondly, uniform stimulus and recording parameters setup should be installed. However, 500 Hz tone burst stimulus is

commonly used for the analysis in literature (29-31) .Up to date there is no still optimum standard stimulus type for the best evaluation.

In summary, this study pointed out that oVEMP with wide-band chirp stimulus have shorter latency and higher amplitude and more clear waveform morphology with higher ratio of response with respect to click and tone burst. In the light of these unique results with chirp stimulus, utricular irregular afferent neurons may have similar frequency specific tonotopic organisation as seen in cochlea. Also, with the help of further comprehensive studies of peripheral vestibular diseases with oVEMP using the chirp stimulus, the stability, feasibility and validity of this stimulus can be understood much more evidently.

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

Financial Disclosure: There are no financial supports.

Ethical approval: Diskapi Yildirim Beyazit Training and Research Hospital, (03.2016, 27/06).

Banu Bas ORCID: 0000-0002-2521-4545
Kemal Keseroglu ORCID: 0000-0001-6497-2413
Serap Er ORCID: 0000-0002-7093-3979
Ali Ozdek ORCID: 0000-0002-3746-8462
Mehmet Hakan Korkmaz ORCID: 0000-0001-8732-3061

REFERENCES

1. Rosengren SM, McAngus Todd NP, Colebatch JG. Vestibular-evoked extraocularpotentials produced by stimulation with bone-conducted sound.Clin Neurophysiol 2005;116:1938-48.
2. Todd NP, Rosengren SM, Aw ST, et al Ocular vestibular evoked myogenic potentials (OVEMPs) produced by air- and bone-conducted sound. Clin Neurophysiol 2007;118:381-90.
3. Kantner C, Gürkov R. Characteristics and clinical applications of ocular vestibular evoked myogenic potentials. Hear Res 2012; 294:55-63.
4. Weber KP, Rosengren SM. Clinical utility of ocular vestibular-evoked myogenic potentials (oVEMPs). Curr Neurol Neurosci Rep 2015;15:22.
5. Curthoys IS, Vulovic V, Burgess AM, et al. Neural basis of new clinical vestibular tests: otolithic neural responses to sound and vibration. Clin Exp Pharmacol Physiol 2014;41:371-80.
6. Kantner C, Hapfelmeier A, Drexl M, et al The effects of rise/fall time and plateau time on ocular vestibular evoked myogenic potentials.Eur Arch Otorhinolaryngol 2014;271:2401-7.
7. Murnane OD, Akin FW, Kelly KJ, et al. Effects of stimulus and recording parameters on the air conduction ocular vestibular evoked myogenic potential. J Am Acad Audiol 2011;22:469-80.
8. Rosengren SM, Govender S, Colebatch JG. Ocular and cervical vestibular evoked myogenic potentials produced by air- and bone-conducted stimuli: comparative properties and effects of age. Clin Neurophysiol 2011;122:2282-9.
9. Kumar K, Bhat JS, Sequeira NM, et al.Ageing Effect on Air-Conducted Ocular Vestibular Evoked Myogenic Potential. Audiol Res 2015;315:121.
10. Elberling C, Don M. A direct approach for the design of chirp stimuli used for the recording of auditory brainstem responses. J Acoust Soc Am 2010; 128:2955-64.
11. Dau T, Wegner O, Mellert V, et al. Auditory brainstem responses with optimized chirp signals compensating basilar-membrane dispersion. J Acoust Soc Am 2000; 107:1530-40.
12. Wang BC, Liang Y, Liu XL, et al. Comparison of chirp versus click and tone pip stimulation for cervical vestibular evoked myogenic potentials. Eur Arch Otorhinolaryngol 2014; 271:3139-46.
13. Özgür A, Çelebi Erdivanlı Ö, Özergin Coşkun Z, et al. Comparison of Tone Burst, Click and Chirp Stimulation in Vestibular Evoked Myogenic Potential Testing in Healthy People. J Int Adv Otol 2015;11:33-5.
14. Walther LE, Cebulla M. Band limited chirp stimulation in vestibular evoked myogenic potentials. Eur Arch Otorhinolaryngol 2016;273:2983-91.
15. Perez N, Rama-Lopez J. Head-impulse and caloric tests in patients with dizziness. Otol Neurotol 2003; 24:913-7.
16. Murofushi T. Clinical application of vestibular evoked myogenic potential (VEMP). Auris Nasus Larynx 2016; 43:367-76.
17. Curthoys IS, Grant JW, How does high-frequency sound or vibration activate vestibular receptors? Exp Brain Res 2015; 233:691-9.
18. Curthoys IS, Vulovic V, Manzari L. Ocular vestibular-evoked myogenic potential (oVEMP) to test utricular function: neural and oculomotor evidence. Acta Otorhinolaryngol Ital 2012;32:41-5.
19. Piker EG, Jacobson GP, Burkard RF, et al. Effects of age on the tuning of the cVEMP and oVEMP. Ear Hear 2013;34:65-73.
20. Piker EG, Jacobson GP, McCaslin DL, et al. Normal characteristics of the ocular vestibular evoked myogenic potential. J Am Acad Audiol 201;22:222-30.
21. Basta D, Todt I, Ernst A. Characterization of age-related changes in vestibular evoked myogenic potentials. J Vestib Res 2007;17:93-8.
22. Su HC, Huang TW, Young YH, Cheng PW, Aging effect on vestibular evoked myogenic potential. Otol Neurotol 2004;25:977-80.
23. Neuhauser HK, Epidemiology of vertigo. Curr Opin Neurol 2007;20:40-6.
24. Bargen GA, Chirp-Evoked Auditory Brainstem Response in Children: A Review. Am J Audiol 2015; 24;573-83.
25. Smith ME, Schuck JB, Gilley RR, et al.Structural and functional effects of acoustic exposure in goldfish: evidence for tonotopy in the teleost saccule. BMC Neurosci 2011;15:12-9.
26. Sung PH, Cheng PW, Young YH. Effect of gender on ocular vestibular-evoked myogenic potentials via various stimulation modes. Clin Neurophysiol 2011; 122:183-7.
27. Ozdek A, Bayır O, Tatar EC, et al. Comparison of tone burst versus logon stimulation for vestibular evoked myogenic potentials. Eur Arch Otorhinolaryngol 2012; 269:1425-9.
28. Viciana D, Lopez-Escamez JA. Short tone bursts are better than clicks for cervical vestibular-evoked myogenic potentials in clinical practice. Eur Arch Otorhinolaryngol 2012;269:1857-63.
29. Akin FW, Murnane OD, Proffitt TM. The effects of click and tone-burst stimulus parameters on the vestibular evoked myogenic potential (VEMP). J Am Acad Audiol 2003;14:500.