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Original Article

Comparison of Compressed High-Intensity Radar Pulse and Tone Burst Stimulation in Vestibular Evoked Myogenic Potentials in Acute Peripheral Vestibular System Pathologies

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BACKGROUND: It is ascertained that the compressed high-intensity radar pulse (CHIRP) is an effective stimulus in auditory electrophysiology. This study aims to investigate whether Narrow Band Level Specific Claus Elberling Compressed High-Intensity Radar Pulse (NB LS CE-CHIRP) stimulus is an effective stimulus in the vestibular evoked myogenic potentials test.

METHODS: A case-control study was designed. Fifty-four healthy participants with no vertigo complaints and 50 patients diagnosed with acute peripheral vestibular pathology were enrolled in this study. Cervical and ocular vestibular evoked myogenic potential tests (cervical vestibular evoked myogenic potentials and ocular vestibular evoked myogenic potentials) with 500 Hz tone burst and 500 Hz Narrow Band Level Specific CE-CHIRP stimulations were performed on all participants. In addition, cervical vestibular evoked myogenic potentials and ocular vestibular evoked myogenic potentials tests with 1000 Hz tone burst and 1000 Hz Narrow Band Level Specific CE-CHIRP were performed on 24 Meniere's disease patients. P1 latency, N1 latency, amplitude, threshold, and the asymmetry ratio of responses were recorded.

RESULTS: In healthy participants, with CHIRP stimulus, shorter P1 latency ($P < .001$), shorter N1 latency ($P < .001$), and lower threshold ($P = .003$) were obtained in the cervical vestibular evoked myogenic potentials test; shorter P1 latency ($P < .001$), shorter N1 latency ($P < .001$), higher amplitude ($P < .001$), and lower threshold ($P < .001$) were obtained in ocular vestibular evoked myogenic potentials test. In symptomatic ears of patients, with CHIRP stimulus, shorter P1 latency ($P < .001$), shorter N1 latency ($P < .001$), and lower threshold ($P = .013$ in cervical vestibular evoked myogenic potentials; $P = .015$ in ocular vestibular evoked myogenic potentials) were obtained in cervical vestibular evoked myogenic potentials and ocular vestibular evoked myogenic potentials tests. In asymptomatic ears of patients, with CHIRP stimulus, shorter P1 latency ($P < .001$) and shorter N1 latency ($P < .001$) were obtained in the cervical vestibular evoked myogenic potentials test; shorter P1 latency ($P < .001$), shorter N1 latency ($P < .001$), higher amplitude ($P < .001$), and lower threshold ($P = .006$) were obtained in ocular vestibular evoked myogenic potentials test.

CONCLUSION: Our results suggest that due to higher response rates, shorter latencies, higher amplitude, and lower threshold values, the Narrow Band Level Specific CE-CHIRP stimulus is an effective stimulus for both cervical vestibular evoked myogenic potentials and ocular vestibular evoked myogenic potentials tests.

KEYWORDS: Cervical vestibular evoked myogenic potentials (cVEMP), ocular vestibular evoked myogenic potentials (oVEMP), CHIRP, Tone burst

INTRODUCTION

Vestibular evoked myogenic potentials (VEMP) are short-latency muscle reflex responses triggered by stimulation of peripheral otolith organs by sound, vibration, or electrical stimulation. The inhibitory myogenic response measured over the sternocleidomastoid muscle (SCM) is cervical VEMP (cVEMP); the excitatory myogenic response measured over the extraocular muscles, the inferior oblique, is the ocular VEMP (oVEMP).

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Cervical VEMP is characterized by a biphasic wave in the form of one positive wave (P1/P13) occurring at an average of 13th millisecond and one negative wave (N1/N23) occurring at an average of 23rd millisecond. Ocular VEMP is characterized by a biphasic wave in the form of 1 negative wave (N1/N10) occurring at an average of 10th millisecond and 1 positive wave (P1/P16) occurring at an average of 16th millisecond.[1]

Cervical VEMP responses originate from the saccule. The afferents extend from the Scarpa's ganglion to the inferior branch of the vestibular nerve. The fibers terminate at interneurons in the medial and lateral vestibular nuclei. Efferents extend, from the vestibular nuclei to the motor nucleus of the accessory nerve innervating the SCM, through the vestibulospinal tract. Cervical VEMP evaluates saccule function, inferior vestibular nerve, and vestibulocolic (otolith-cervical) reflex.

Ocular VEMP responses originate from the utricle. Afferents elongate through the superior vestibular nerve to the vestibular nuclei and terminate in the vestibulo-ocular reflex afferents. Efferents extend from the vestibular nuclei to the motor neurons of the oculomotor and trochlear cranial nerves via the medial longitudinal fasciculus bilaterally. Fibers originating from these motor neurons terminate in the extraocular muscles. Ocular VEMP evaluates utricle function, superior vestibular nerve, and vestibulo-ocular (otolith-ocular) reflex.[2]

Acoustic stimulus is the most common VEMP stimulus modality. Stimulus type affects the VEMP responses. Click, tone burst, and tone pip are commonly used stimuli in the VEMP test. Colebatch used a 0.1 ms square wave click stimulus in the initial report on cVEMPs.[3] Click stimulus has fast onset and stimulates across the range of frequencies of 1-4 k Hz. Saccule has frequency tuning at 500-1000 Hz.[4] Therefore, a 500 Hz tone burst is the optimal commonly used stimulus in the VEMP test.[5]

Compressed high-intensity radar pulse (CHIRP) is an acoustic stimulus in which frequency varies with time; it either increases (up-CHIRP) or decreases (down-CHIRP). It is designed for all frequency parts on the basilar membrane to reach maximum depolarization simultaneously and generate synchronized firing of the nerve fibers. CHIRP provides simultaneous stimulation of the basilar membrane by temporal distribution of frequencies; thereby compensating for cochlear delay along with the cochlear traveling wave.[6]

CHIRP stimulus is an effective stimulus in auditory electrophysiology. CHIRP stimulus enables larger amplitude waveforms that are easier to detect with increased synchronization and decreases test time in auditory brainstem responses (ABR).[7] CHIRP stimulus provides accurate hearing-loss measurement in a short time in auditory steady-state responses (ASSR).[8] CHIRP evoked compound action potential (CAP) is a comprehensive neural measure in cochlear implant patients with residual hearing.[9]

Vestibular evoked myogenic potential in responses to CHIRP stimulus was reported in recent studies. However, a limited number of studies are available in the literature. Different stimulus parameters were used in these studies. Almost all of these studies were conducted on healthy individuals. The sample size of some of these studies is too small. The results of these studies differ.

The current study aimed to compare the CHIRP and tone burst stimulation in VEMPs in acute peripheral vestibular system pathologies.

METHODS

Participants

Fifty patients (29 females, 21 males; with a mean age of 53.24 ± 11.9 years, range 20-75 years) diagnosed with acute peripheral vestibular system pathology, and 54 sex and age-matched healthy participants with no vertigo complaints were enrolled in this study. The patient group consists of 24 Meniere's disease/endolymphatic hydrops (ELH), 14 benign paroxysmal positional vertigo (BPPV), and 12 vestibular neuritis (VN) patients.

Meniere's disease was diagnosed according to the Guidelines of the Committee on Hearing & Equilibrium of the American Academy of Otolaryngology-Head and Neck Surgery.[10] Diagnosis of Meniere's disease was confirmed by demonstration of hearing loss with pure tone audiometry, videonystagmography (VNG), binaural bithermal caloric test, electrocochleography (ECochG) findings, history of episodic vertigo attacks, and clinical symptoms such as tinnitus, aural fullness. Diagnosis of BPPV is confirmed by Dix-Hallpike and Roll maneuver with video Frenzel goggles. Diagnosis of vestibular neuritis is confirmed by VNG, vHIT, VEMP, binaural bithermal caloric test findings, clinical symptoms, and anamnesis.

After diagnostic procedure, each subject underwent neurotologic examination, including 125-8000 Hz pure tone audiometry with Interacoustics Clinical Audiometer AC40, tympanometry with GSI Tympstar Version 2™, VEMP tests with Interacoustics Eclipse EP25 in Başkent University Department of Otorhinolaryngology between February 2020 and April 2021.

The exclusion criteria were all ear problems that cause conductive hearing loss.

This study was carried out with the approval of Baskent University Medical and Health Sciences Research Council (Project no: KA20/20) and Non-Interventional Clinical Research Ethics Committee (Decision No. 20/17, dated Feb 02, 2020). Both verbal and written informed consent were obtained from all participants.

Vestibular Evoked Myogenic Potentials Technique

Electrode sites were cleaned up with NuPrep® Skin Prep Gel. Ambu® Neuroline 720 (REF: 72000-S/25) disposable self-adhesive surface electrodes were used.

In the cVEMP test, the active electrodes were placed on the center of SCM, the monitor electrode was placed in the suprasternal notch; the ground electrode was placed on the forehead. Participants were instructed to turn their heads to the opposite side of the ear being tested. Effective contraction of the SCM muscle was maintained throughout the feedback of the software.

In the oVEMP test, the active electrodes were placed 3-4 mm below the inferior eyelid (on the inferior oblique muscle), the monitor electrode was placed on the chin, and the ground electrode was placed on the forehead. In cases where an electrode cannot be placed on the chin, the monitor electrode was placed 2 cm below the active

electrodes. Participants were instructed to look at the predetermined point, forming an angle of about 30° with the horizontal axis.

The impedance of electrodes was set to <3 kΩ. Stimuli were delivered through 3M™ E-A-RTONE™ Insert Earphone and disposable 3M™ E-A-RLINK ™ 3A Foam Eartips.

Cervical and ocular vestibular evoked myogenic potential tests with 500 Hz tone burst and 500 Hz Narrow Band Level Specific (NB LS) CE-CHIRP stimulations were performed on all participants.

It has been reported that frequency tuning changes in Meniere's disease and the best responses are obtained around 1000 Hz.[11] Therefore, cVEMP and oVEMP tests with 1000 Hz tone burst and 1000 Hz NB LS CE-CHIRP were performed on 24 Meniere's disease/ELH patients.

In order to eliminate the effect of muscle fatigue, stimuli were delivered in random order. Polarity was rarefaction for all stimuli. For tone bursts, rise/ fall and plateau time were 2 ms (2-2-2 cycles). The filter was set between 10 and 1000 Hz. The stimulus rate was set to 5.1 Hz. In each recording, a total of 200 stimuli were averaged.

All stimuli were presented at 100 dB nHL. In the resulting waveform, P1-N1 was determined for cVEMP; N1-P1 was determined for oVEMP. P1 latency, N1 latency, P1-N1 amplitude, normalized P1-N1 amplitude, and the asymmetry ratio were measured in cVEMP; N1 latency, P1 latency, N1-P1 amplitude, and the asymmetry ratio were measured in oVEMP. The threshold was determined by reducing the stimulus intensity by 10 dB until the wave morphology deteriorated (Figures 1-4).

The data were examined in 3 groups: the control group (formed by healthy individuals), the symptomatic ear group (formed by the symptomatic ears of patients), and the asymptomatic ear group (formed by asymptomatic ears of patients).

Statistical Analysis

Data were analyzed with Statistical Package for Social Sciences (SPSS) version 25 software. The distribution of the values was analyzed using the Shapiro–Wilk test. When normal distribution was observed, values were compared using paired *t*-test. Otherwise, values were compared with Wilcoxon signed-rank test. In intergroup evaluation, when normal distribution was observed, groups were compared with one-way ANOVA. Otherwise, groups were compared with Kruskal–Wallis tests. The results were evaluated in the 95% confidence interval and the significance was evaluated as $P < .05$.

Power analysis, in which vestibular system pathologies were planned as three separate groups (Meniere's disease, BPPV, vestibular neuritis), was applied. In the current study, a sufficient number of patients could not be reached due to pandemic conditions. The patients were collected in a single group. The findings of healthy individuals were previously reported by Aydin et al.[12]

RESULTS

Pure Tone Audiometry

125-8000 Hz pure tone audiometry (PTA) threshold range was 0-115 dB in the control group, 0-95 dB in the symptomatic ear group, and 0-120 dB in the asymptomatic ear group.

In contrast, 125-8000 Hz PTA threshold range was 0-60 dB in BPPV patients, 0-70 dB in VN patients; and the low frequency (125-500 Hz) PTA threshold range was 0-115 dB in Meniere's disease/ ELH patients.

Response Rate

The response rate was 98.4% in the control group, 84.8% in the symptomatic ear group, and 92.2% in the asymptomatic ear group. The response rate was 87.5% in the Meniere's disease/ELH

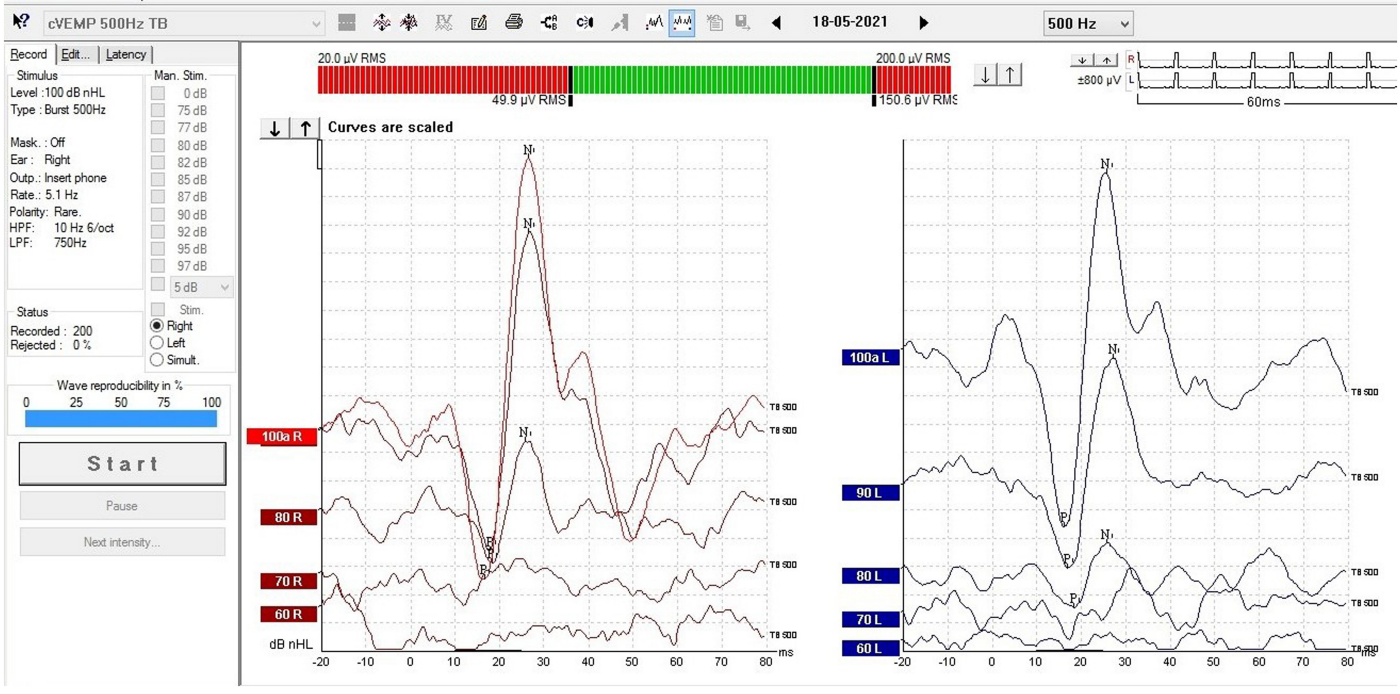

Figure 1. Cervical VEMP recording with 500 Hz TB. VEMP, vestibular evoked myogenic potentials.

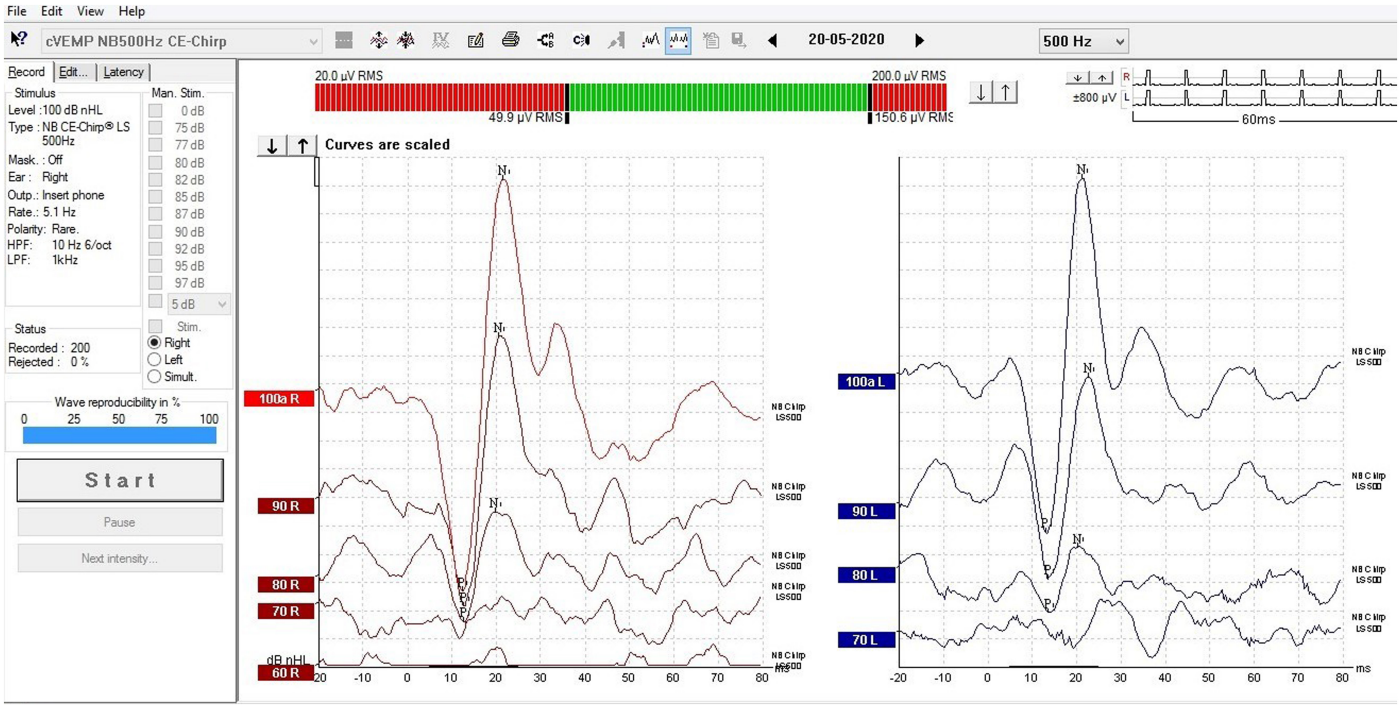

Figure 2. Cervical VEMP recording with 500 Hz Narrow Band Level Specific CE-CHIRP. VEMP, vestibular evoked myogenic potentials.

patients, 84.9% in the symptomatic ears of Meniere's disease/ELH patients, and 90% in the nonsymptomatic ears of Meniere's disease/ELH patients. The response rate was 94.6% in the BPPV patients, 89.3% in the symptomatic ears of BPPV patients, and 100% in the asymptomatic ears of BPPV patients. The response rate was 70.8% in the vestibular neuritis patients, 58.3% in the symptomatic ears of VN patients, and 83% in the asymptomatic ears of VN patients. Response rates according to tone burst and CHIRP stimuli are given in Tables 1 and 2.

Vestibular Evoked Myogenic Potential Responses

Further, 500 Hz latency, amplitude, and threshold values of all groups are given in Table 3, and 1000 Hz latency, amplitude, and threshold values of the Meniere's disease/ELH patients are given in Table 4.

In the control group, statistically significant shorter cVEMP P1 latency ($P < .001$), shorter cVEMP N1 latency ($P < .001$), lower cVEMP threshold ($P = .003$), shorter oVEMP P1 latency ($P < .001$), shorter oVEMP N1 latency ($P < .001$), higher oVEMP amplitude ($P < .001$), and lower

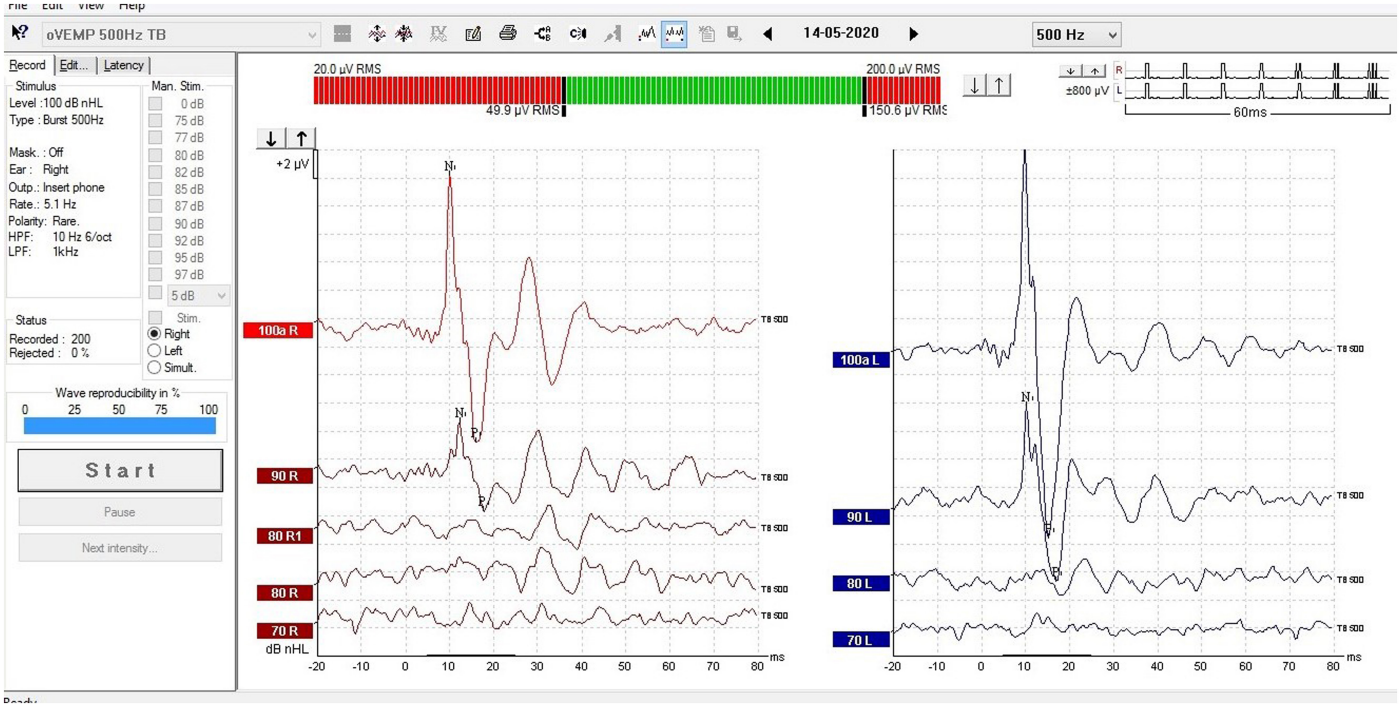

Figure 3. Ocular VEMP recording with 500 Hz TB. VEMP, vestibular evoked myogenic potentials.

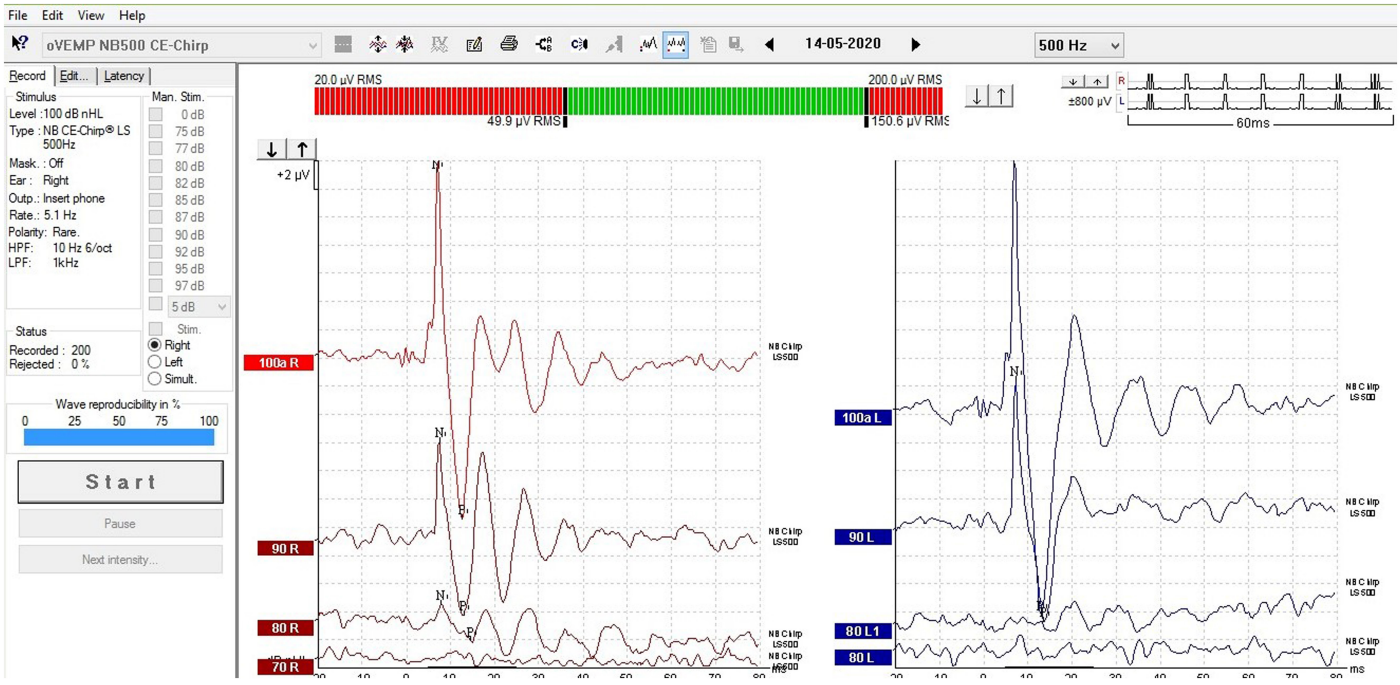

Figure 4. Ocular VEMP recording with 500 Hz Narrow Band Level Specific CE-CHIRP. VEMP, vestibular evoked myogenic potentials.

oVEMP threshold ($P < .001$) were obtained with CHIRP stimulus (Wilcoxon signed-rank test; $P < .01$). In the control group, there was no significant difference between tone burst and CHIRP stimuli in cVEMP amplitude values (Paired samples t-test; $P = .056$).

In the symptomatic ear group, statistically significant shorter cVEMP P1 latency ($P < .001$), shorter cVEMP N1 latency ($P < .001$), lower cVEMP threshold ($P = .013$), shorter oVEMP P1 latency ($P < .001$), shorter oVEMP N1 latency ($P < .001$), and lower oVEMP threshold ($P = .015$) were obtained with CHIRP stimulus. In the symptomatic ear group, there was no statistically significant difference between tone burst and CHIRP stimuli in cVEMP amplitude ($P = .07$) and oVEMP amplitude ($P = .051$) values.

In the asymptomatic ear group, statistically significant shorter cVEMP P1 latency ($P < .001$), shorter cVEMP N1 latency ($P < .001$), shorter oVEMP P1 latency ($P < .001$), shorter oVEMP N1 latency ($P < .001$), higher oVEMP amplitude ($P < .001$), and lower oVEMP threshold ($P = .006$) were obtained with CHIRP stimulus. In the asymptomatic ear group, there was no statistically significant difference between tone burst and CHIRP stimuli in cVEMP amplitude ($P = .122$) and cVEMP threshold ($P = .132$) values.

Table 1. Vestibular Evoked Myogenic Potentials Response Rates of Participants

Study Groups	cVEMP		oVEMP	
	500 Hz Tone Burst	500 Hz NB LS CE-CHIRP	500 Hz Tone Burst	500 Hz NB LS CE-CHIRP
Control group	97%	98%	99%	99%
Symptomatic ear group	90%	94%	88%	88%
Asymptomatic ear group	97%	98%	95%	99%

cVEMP, cervical vestibular evoked myogenic potentials; oVEMP, ocular vestibular evoked myogenic potentials; NB LS CE-CHIRP, Narrow Band Level Specific Claus Elberling Compressed High-Intensity Radar Pulse.

In symptomatic ears of Meniere's disease/ELH patients, statistically significant, shorter cVEMP P1 latency ($P < .001$), shorter cVEMP N1 latency ($P < .001$), shorter oVEMP P1 latency ($P < .001$), and shorter oVEMP N1 latency ($P = .002$) were obtained with 1000 Hz CHIRP stimulus. In the symptomatic ears of Meniere's disease/ELH patients, there was no statistically significant difference between tone burst and CHIRP stimuli in cVEMP threshold ($P = .414$), oVEMP amplitude ($P = .906$), and oVEMP threshold ($P = .102$) values.

In the asymptomatic ears of Meniere's disease /ELH patients, statistically significant, shorter cVEMP P1 latency ($P < .001$), shorter cVEMP N1 latency ($P < .001$), higher amplitude ($P < .001$), shorter oVEMP P1 latency ($P < .001$), and shorter oVEMP N1 latency ($P < .001$) were obtained with 1000 Hz CHIRP stimulus. In the asymptomatic ears of Meniere's disease /ELH patients, there was no statistically significant difference between tone burst and CHIRP stimuli in cVEMP threshold ($P = .999$), oVEMP amplitude ($P = .397$), and oVEMP threshold ($P = .257$) values.

Asymmetry Ratio

In the control group, the asymmetry ratio was 0.13 in 500 Hz tone burst cVEMP test, 0.11 in 500 Hz NB LS CHIRP cVEMP test, 0.20 in 500 Hz tone burst oVEMP test, and 0.17 in 500 Hz NB LS CHIRP oVEMP test.

In Meniere's disease /ELH patients, the asymmetry ratio was 0.18 in 500 Hz tone burst cVEMP test, 0.19 in 500 Hz NB LS CHIRP cVEMP test, 0.18 in 1000 Hz tone burst cVEMP test, 0.16 in 1000 Hz NB LS CHIRP cVEMP test, 0.23 in 500 Hz tone burst oVEMP test, 0.18 in 500 Hz NB LS CHIRP oVEMP test, 0.24 in 1000 Hz tone burst oVEMP test, and 0.18 in 1000 Hz NB LS CHIRP oVEMP test.

Table 2. Vestibular Evoked Myogenic Potentials Response Rate of Meniere's Disease/Endolymphatic Hydrops Patients in 1000 Hz Stimuli Tests

Meniere Disease/ELH Patients	cVEMP		oVEMP	
	1000 Hz Tone Burst	1000 Hz NB LS CE-CHIRP	1000 Hz Tone Burst	1000 Hz NB LS CE-CHIRP
Symptomatic ears of Meniere disease patients	85%	85%	95%	95%
Asymptomatic ears of Meniere's disease patients	85%	85%	80%	90%

cVEMP, cervical vestibular evoked myogenic potentials; ELH, endolymphatic hydrops patients; oVEMP, ocular vestibular evoked myogenic potentials; NB LS CE-CHIRP, Narrow Band Level Specific Claus Elberling Compressed High-Intensity Radar Pulse.

Table 3. Vestibular Evoked Myogenic Potentials Results of Study Groups in 500 Hz Stimuli Tests

		cVEMP		oVEMP	
		500 Hz Tone Burst (Mean ± SD)	500 Hz LS CE-CHIRP (Mean ± SD)	500 Hz Tone Burst (Mean ± SD)	500 Hz LS CE-CHIRP (Mean ± SD)
Control group	P1 (ms) ($P < .001$ for both cVEMP and oVEMP)	16.05 ± 1.7	12.42 ± 1.6	16.51 ± 1.5	12.92 ± 1.9
	N1 (ms) ($P < .001$ for both cVEMP and oVEMP)	25.93 ± 21	21.56 ± 1.9	10.65 ± 1.0	7.76 ± 1.5
	Amplitude (μV) ($P < .001$ for oVEMP)	121.66	102.63	15.15±11.0	21.61±13.8
	Normalized amplitude (μV) ($P = .056$ for cVEMP)	1.52 ± 0.6	1.45 ± 0.5	-	-
	Threshold (dB) ($P = .003$ for cVEMP , $P < .001$ for oVEMP	83.71 ± 8.0	82.17 ± 8.0	91.43 ± 7.1	86.48 ± 6.8
Symptomatic ear group	P1 (ms) ($P < .001$ for both cVEMP and oVEMP)	15.82 ± 1.5	12.40 ± 1.4	16.26 ± 3.2	13.26 ± 1.3
	N1 (ms) ($P < .001$ for both cVEMP and oVEMP)	25.12 ± 2.0	21.04 ± 2.2	11.03 ± 1.8	8.24 ± 1.3
	Amplitude (μV) ($P = .051$ for oVEMP)	62.39	59.36	9.96 ± 7.7	11.26 ± 10.7
	Normalized amplitude (μV) ($P = .07$ for cVEMP)	0.91 ± 0.5	0.94 ± 0.4	-	-
	Threshold (dB) ($P = .013$ for cVEMP, $P = .015$ for oVEMP)	90 ± 6.5	88.57 ± 7.5	95 ± 6.9	91.40 ± 9.4
Asymptomatic ear group	P1 (ms) ($P < .001$ for both cVEMP and oVEMP)	15.64 ± 1.5	11.88 ± 1.3	17.04 ± 2.5	13.07 ± 1.9
	N1 (ms) ($P < .001$ for both cVEMP and oVEMP)	24.84±2.0	20.72±1.7	11.53 ± 1.7	8.15 ± 1.7
	Amplitude (μV) $P < .001$ for oVEMP)	79.45	86.18	13.21 ± 14.5	18 ± 21.9
	Normalized amplitude (μV) ($P = .122$ for cVEMP)	1.12 ± 0.6	1.18 ± 0.5	-	-
	Threshold (dB) ($P = .132$ for cVEMP, $P = .006$ for oVEMP)	88.26 ± 8.2	87.45 ± 7.7	92.44±7.7	88.96±8.1

cVEMP, cervical vestibular evoked myogenic potentials; oVEMP, ocular vestibular evoked myogenic potentials; LS CE-CHIRP, Level Specific Claus Elberling Compressed High-Intensity Radar Pulse; SD, standard deviation.

Table 4. Vestibular Evoked Myogenic Potential Results of Meniere's Disease/Endolymphatic Hydrops Patients in 1000 Hz Stimuli Tests

		cVEMP		oVEMP	
		1000 Hz Tone Burst (Mean ± SD)	1000 Hz LS CE-CHIRP (Mean ± SD)	1000 Hz Tone Burst (Mean ± SD)	1000 Hz LS CE-CHIRP (Mean ± SD)
Symptomatic ears of Meniere's disease/ELH patients	P1 (ms) ($P < .001$ for both cVEMP and oVEMP)	15.06 ± 1.7	13.27 ± 1.6	15.53 ± 1.7	13.54 ± 2.0
	N1 (ms) ($P < .001$ for cVEMP, $P = .002$ for oVEMP)	22.69 ± 1.9	20.78 ± 2.1	10.61 ± 1.4	9.05 ± 1.7
	Amplitude (μV) ($P < .001$ for cVEMP, $P = .906$ for oVEMP)	51.45	42.68	11.68 ± 11.1	11.31 ± 10.3
	Normalized amplitude (μV) ($P = .024$ for cVEMP)	0.82 ± 0.5	0.68 ± 0.4	-	-
	Threshold (dB) ($P = .414$ for cVEMP, $P = .102$ for oVEMP)	93.13 ± 7.0	92.35 ± 6.6	95.88 ± 6.2	94.21 ± 6.9
Asymptomatic ears of Meniere's disease/ELH patients	P1 (ms) ($P < .001$ for both cVEMP and oVEMP)	14.75 ± 1.7	12.92 ± 1.7	15.60 ± 0.9	13.69 ± 1.2
	N1 (ms) ($P < .001$ for both cVEMP and oVEMP)	22.78 ± 2.0	20.65 ± 1.7	10.31 ± 1.2	8.22 ± 0.8
	Amplitude (μV) ($P = .397$ for oVEMP)	80.61	63.42	13.85 ± 7.5	15.76 ± 11.4
	Normalized amplitude (μV) ($P < .001$ for cVEMP)	1.07 ± 0.4	0.88 ± 0.4	-	-
	Threshold (dB) ($P = .999$ for cVEMP, $P = .257$ for oVEMP)	93.53 ± 7.0	93.53 ± 7.0	93.57 ± 6.3	92.22 ± 8.1

cVEMP, cervical vestibular evoked myogenic potentials; oVEMP, ocular vestibular evoked myogenic potentials; LS CE-CHIRP, Level Specific Claus Elberling Compressed High-Intensity Radar Pulse; SD, standard deviation.

In BPPV patients, the asymmetry ratio was 0.12 in 500 Hz tone burst cVEMP test, 0.14 in 500 Hz NB LS CHIRP cVEMP test, 0.23 in 500 Hz tone burst oVEMP test, and 0.23 in 500 Hz NB LS CHIRP oVEMP test.

In vestibular neuritis patients, the asymmetry ratio was 0.15 in 500 Hz tone burst cVEMP test, 0.18 in 500 Hz NB LS CHIRP cVEMP test, 0.18 in 500 Hz tone burst oVEMP test, and 0.24 in 500 Hz NB LS CHIRP oVEMP test.

Intergroup Comparison

In the control group, compared to symptomatic and asymptomatic ear groups, statistically significant higher amplitude ($P < .001$) and lower threshold ($P < .001$) were in the cVEMP test and shorter N1 latency ($P = .006$ for tone burst; $P < .001$ for CHIRP), higher amplitude ($P = .012$ for tone burst; $P < .001$ for CHIRP), and lower threshold ($P = .024$ for tone burst; $P < .001$ for CHIRP) were in oVEMP test for both tone burst and CHIRP stimuli (Kruskal–Wallis test).

DISCUSSION

In the VEMP test, the stimulus that effectively stimulates the neurosensitive structure should be reached. Therefore, the effectiveness of the CHIRP stimulus in VEMP testing is being studied. In the literature, few studies evaluate CHIRP stimuli in VEMP tests (Tables 5 and 6). Different CHIRP stimulus types and parameters were used in these studies. The results of them vary. Most of these studies were conducted on healthy individuals. Vestibular evoked myogenic potential response rates are decreasing in the vestibular system pathologies. However, it is doubtful whether the absence of the response is due to pathology or it is a false negative response. The lack of studies conducted with vestibular system pathologies is a deficiency in the literature. Preceding studies have focused on different aspects of VEMP wave findings, but not all parameters have been reported. Vestibular evoked myogenic potential threshold values have not been reported in the literature.

Including large sample sizes of healthy individuals and patients with vestibular system disorders, achieving high response rates, separate evaluation of symptomatic and asymptomatic ears of patients, both cVEMP and oVEMP evaluation with the CHIRP type not used in the previous studies, and reporting P1 latency, N1 latency, amplitude, threshold, asymmetry ratio values, and response rates were the strengths of the current study.

The cVEMP response rate was between 81.2% and 100% for CHIRP stimuli in previous studies. Shorter P1 and N1 latencies have been

Table 5. Literature Studies Evaluating the CHIRP Stimulus in the cVEMP Test

		Year	N of H	N of P	Age	CH Type	OS	SL (dB)	RR of CH (%)	RR of OS (%)	P1 L CH (ms)	P1 L of OS (ms)	N1 L of CH (ms)	N1 L of OS (ms)	Amp CH (µV)	Amp OS (µV)	Norm Amp CH (µV)	Norm Amp OS (µV)	Th CH (dB)	Th OS (dB)
Wang et al[13]		2013	30	-	24	500 Hz CE-CHIRP	Tone Pip	100	100	100	4.905	11.812	11.877	19.1	14.422	13.334	-	-	-	-
Ozgur et al[14]		2015	39	-	28	500-4000 Hz CHIRP	500 Hz TB	100	89.7	93.5	9.9	15.8	-	-	33	93.5	-	-	-	-
Walther Cebulla[18]		2016	10	-	37.5	CW-VEMP-CHIRP	500 Hz TB	100	90	90	-	-	-	-	233	183.2	-	-	-	-
Cebulla Walther[19]		2019	5	-	38.6	CW-VEMP-CHIRP	-	100	85	-	15.1	-	23.7	-	237	206	-	-	-	-
Moinudeen et al[17]		2020	30	-	22	500 Hz CHIRP	500 Hz TB	100	-	-	12.61	16.4	18.71	22.36	70.15	68.45	-	-	-	-
Murofushi et al[16]		2020	-	16	42.9	LS CE-CHIRP	TB	100	81.2	81.2	14.52	18.1	23.6	28.4	-	-	0.44	0.91	-	-
Ocal et al[15]		2021	50	-	26.7	360-720 Hz CE-CHIRP	500 Hz TB	100	100	100	10.46	16.04	19.21	25	54.95	53.58	-	-	-	-
Aydın et al[12]		2022	56	-	34.6	250-10900 Hz CHIRP	500 Hz TB	105	96.4	92.8	1040	13.95	18.62	22.21	62.63	55.43	1.38	1.2	-	-
Current study	**Controls**		**54**		**40.9**	**500 Hz LS CE-CHIRP**	**500 Hz TB**	**100**	**98**	**97**	**12.42**	**16.05**	**21.56**	**25.93**	**102.63**	**121.66**	**1.45**	**1.52**	**82.17**	**83.71**
	Patients			**50**	**53.3**			**100**	**96**	**93.5**	**12.14**	**11.88**	**20.88**	**24.98**	**72.77**	**70.92**	**1.06**	**1.02**	**88.01**	**89.13**

Amp, amplitude; cVEMP, cervical vestibular evoked myogenic potentials; H, healthy individuals; N, number; Norm, normalized; OS, other stimulus; P, patients; RR, response rate; SL, stimulus level; Th, threshold.

Table 6. Literature Studies Evaluating the CHIRP Stimulus in the oVEMP Test

	Year	N of H	N of P	Age	CH Type	OS	SL (dB)	RR CH (%)	RR OS (%)	P1 L CH (ms)	P1 L OS (ms)	N1 L CH (ms)	N1 L OS (ms)	Amp CH (µV)	Amp OS (µV)	Th CH (dB)	Th OS (dB)
Walther Cebulla[18]	2016	10	-	37.5	250-1000 Hz CW-VEMP-CHIRP	500 Hz TB	100	90	90	-	-	-	-	3.5	2.9	-	-
Karacayli et al[21]	2020	60	-	25.8	500 Hz CE-CHIRP	500 Hz TB	100	100	100	9.81	15.51	5.1	10.63	16.67	12.27	-	-
Bas et al[22]	2020	85	-	36.9	10-10000 Hz CHIRP	TB	105	98.8	94.1	11.22	15.01	5.99	10.06	10.92	7.18	-	-
Mat et al[23]	2021	21	-	36.4	500 Hz CE-CHIRP	500 Hz TB	100	100	100	-	-	-	-	-	-	-	-
Aydın et al[12]	2022	56	-	34.6	250-10900 Hz CHIRP	500 Hz TB	105	96.4	78.5	13.34	16.53	7.59	11.05	3.96	3.19	-	-
Current study	**Controls**	**54**		**40.9**	**500 Hz LS CE-CHIRP**	**500**	**100**	**99**	**99**	**12.92**	**16.51**	**7.76**	**10.65**	**21.61**	**15.15**	**86.48**	**91.43**
	Patients		**50**	**53.3**		**Hz TB**	**100**	**93.5**	**91.5**	**13.65**	**16.65**	**8.2**	**11.28**	**14.63**	**11.59**	**90.18**	**93.72**

Amp, amplitude; H, healthy individuals; L, latency; N, number; Norm, normalized; OS, other stimulus; oVEMP, ocular vestibular evoked myogenic potentials; P, patients; RR, response rate; SL, stimulus level; Th, threshold.

reported with the CHIRP stimulus in the cVEMP test.[13-16,17] However, a study stated that longer P1 and N1 latencies were obtained with CHIRP stimulus.[18] Findings of cVEMP amplitude with CHIRP stimulus are contradictory in the literature. In several studies, higher amplitude values were obtained with CHIRP stimulus.[13,17,18,19] Besides, lower amplitude values were reported in other studies.[14,16,20] Moreover, a study indicated that there was no significant difference between tone burst and CHIRP stimulus results.[15] In the current study, the cVEMP response rate with CHIRP stimulus was higher than as was in the previous studies (Table 1). Considering the age range, quite high response rates were achieved in this study. The findings of the current study are compatible with the literature. Furthermore, P1 and N1 latencies were shorter, and amplitude values were higher than in the previous studies.

The oVEMP response rate was between 90% and 100% for CHIRP stimuli in preceding studies. In the literature, there is no oVEMP study with CHIRP stimulus conducted on vestibular system pathologies. Shorter N1 and P1 latencies, higher-wave amplitudes were reported with CHIRP stimulus in oVEMP in the previous studies.[21-23] On the other hand, a study indicated that no statistically significant difference was found in P1 and N1 latencies between tone burst and CHIRP stimulus responses.[18] In the present study, quite high oVEMP response rates were obtained (Table 1). The findings of the current study were consistent with the literature. The oVEMP amplitude values with both tone burst and CHIRP stimulus are higher than in the preceding studies.

The current study contributes to the literature in several ways. Limited studies are available on this subject. There is no consensus about the effective stimulus in VEMP tests. The necessity of further studies has been emphasized. In the current study, all VEMP parameters were reported with previously unused CHIRP stimulus type in large sample sizes of both healthy individuals and patients with vestibular system disorders for both cVEMP and oVEMP tests. The effect of stimulus in different vestibular system pathologies was assessed. Both cVEMP and oVEMP with 1000 Hz stimuli results are reported in Meniere's disease /ELH patients. Considering the age range, quite high response rates were achieved in both cVEMP and oVEMP tests. Achieving high response rates enables the accurate evaluation of stimulus types and VEMP wave parameters. Higher amplitudes, shorter latencies, lower thresholds, and higher response rates indicate that the NB LS CE-CHIRP effectively stimulates the neurosensitive structure. The hypothesis that the CHIRP is an effective stimulus in VEMP testing was supported.

The limitation of the current study was that it is not evaluated whether the findings correlated with clinical symptoms. Number of subjects with vestibular pathology was too small for making any strong conclusions. Narrow Band Level Specific CE-CHIRP stimulus should be studied with longer follow-up periods in larger patient populations in further studies. It should be investigated whether it provides information in disease monitoring.

CONCLUSION

Due to higher response rates, shorter latencies, higher amplitude, and lower threshold values, NB LS CE-CHIRP is an effective stimulus for both cVEMP and oVEMP tests. In clinical practice, it can be added to the VEMP test battery. In the light of this data, more experience

is needed to support the use of CHIRP stimulus in disease follow-up in acute and remission periods of peripheral vestibular pathologies.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Başkent University, (Approval No: 20/17).

Informed Consent: Informed consent was obtained from each participant included in the study.

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