OPEN

Using Narrow Band CE-Chirps to Elicit Cervical Vestibular Evoked Myogenic Potentials

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Objectives: To compare the effects of Narrow band CE-Chirps (NB CE-Chirps) and tone bursts (TBs) at 500 Hz and 1000 Hz on the amplitudes and latencies in cervical vestibular evoked myogenic potentials (cVEMPs).

Design: Thirty-one healthy adult volunteers of varying ages were tested by air conduction at 95 dB nHL. Recording conditions were randomized for each participant and each modality was tested twice.

Results: NB CE-Chirps showed larger corrected amplitudes than TBs at 500 Hz ($p < 0.001$) which were themselves larger than NB CE-Chirps and TBs at 1000 Hz ($p < 0.001$). In older volunteers, NB CE-Chirps 500 and 1000 Hz had significantly higher response rates than TBs 500 Hz ($p = 0.039$). A negative correlation was observed between the corrected amplitudes and the age of the participants regardless of the stimulus and the frequency studied. The p13 and n23 latencies were not correlated with the age of the subjects.

Conclusions: NB CE-Chirps at 500 Hz improved the corrected amplitudes of waveforms in cVEMPs as a result of a better frequency specificity compared with TBs. In the elderly, eliciting cVEMPs at a frequency of 1000 Hz might not be necessary to improve response rates with NB CE-Chirps. Additional studies including a higher number of healthy participants and patients with vestibular disorders are required to confirm these observations.

Key words: cVEMP, Elderly, Frequency tuning, Narrow band CE-Chirp, Tone Burst, 1000 Hz frequency.

Abbreviations: AEP = auditory-evoked potential; ASSR = auditory steady state response; CA = corrected amplitude; cVEMP = cervical vestibular-evoked myogenic potential; CW-VEMP-Chirp = Cebulla Walther-VEMP-Chirp; dB = Decibel; dB A = A-weighted decibel sound pressure level; EMG = electromyography; Hz = Hertz; IAAR = interaural asymmetry ratio; ISO = International Organization for Standardization; LAeq = equivalent sound energy exposure; ms = millisecond; µV = microvolt; NB CE-Chirp = Narrow band Claus Elberling-Chirp; oVEMP = ocular vestibular evoked myogenic potential; Q1 = first quartile; Q3 = third quartile; SCM = sternocleidomastoid; TB = tone burst; VEMP = vestibular evoked myogenic potential.

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INTRODUCTION

Vestibular evoked myogenic potentials (VEMPs) are used to assess otolithic organs and otolith-mediated pathways (Colebatch et al. 2016; Rosengren et al. 2019). Cervical vestibular evoked myogenic potentials (cVEMPs) are myogenic reflexes of saccular origin (Colebatch et al. 1994; Papathanasiou et al. 2014). They are elicited by brief and loud stimulation by either air or bone, or by galvanic-conducted stimulation (Curthoys 2010; Rosengren et al. 2010, 2019). The recording of the myogenic response is usually performed on the contracted ipsilateral sternocleidomastoid (SCM) muscle (Papathanasiou et al. 2014; Rosengren et al. 2019). The activation of the saccule generates an inhibitory reflex on this muscle (Colebatch and Rothwell 2004). Air-conducted tone bursts (TBs) are usually used (Rosengren et al. 2019). Narrow band CE-Chirps (NB CE-Chirps) are other limited frequency range stimuli delivering short and intense sounds (Rodrigues et al. 2013). We have recently shown in a group of healthy volunteers that NB CE-Chirps presented by air conduction elicited larger n1-p1 amplitudes in ocular vestibular evoked myogenic potentials (oVEMPs) than TBs at 500 Hz (Mat et al. 2021). Larger amplitudes could be due to a greater frequency specificity of NB CE-Chirps 500 Hz over TB 500 Hz (Johnson and Brown 2005; Harte et al. 2007; Ferm et al. 2013; Ferm and Lightfoot 2015). This looks promising to reduce intensity required to elicit oVEMPs and minimize the risk of cochlear damage when performing the test. Moreover, this stimulus might differentiate more precisely a falsely absent response to a patient with utricular disorder; especially in the elderly in whom recording responses are more difficult to obtain (Welgampola and Colebatch 2001b). Indeed, it is estimated that oVEMPS and cVEMPs responses may be absent in 46% and 10% of healthy subjects after 50 years, respectively, and up to 67% and 32% after 70 years, respectively (Piker et al. 2015). Also, a frequency tuning to 1000 Hz has been described in oVEMPs and cVEMPs for older people (Taylor et al. 2012; Piker et al. 2013).

Very few studies have compared NB CE-Chirps with TBs in cVEMPs and have provided contradictory results regarding their advantages for optimizing the amplitudes (Wang et al. 2014; Ocal et al. 2021). The purpose of this study was to compare the amplitudes values obtained in cVEMPs with TBs and NB CE-Chirps at the frequency of 500 Hz and 1000 Hz in a group of healthy subjects of varying ages.

METHODS

Subjects

A group of 31 healthy volunteers with no otologic or neuromuscular disorder were included in this prospective study. We have deliberately chosen to include subjects of various ages (15 men, 16 women; median = 40 years, Q1−Q3= 23−57 years, range = 19–73 years).

Exclusion criteria were identified by means of anamnesis and a series of pre-tests whose calibration was checked before the start of the study (Table 1): micro-otoscopy (Zeiss OPMI Pico,

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TABLE 1. Exclusion criteria

Exclusion Criteria	Definition of the Criteria
Conductive or mixed hearing loss	Rinne strictly higher than 10 dB on one of the tested frequencies
Suspicion of retrocochlear pathology	Discrepancy between speech audiometry and pure-tone audiometry
Asymmetric neurosensory hearing loss	Asymmetry higher than 15 dB in comparison with the average frequencies 500, 1000, 2000, and 4000 Hz (Vannson et al. 2015)
Previous otologic problems or balance problems	
Cervical disease	
Neurological or muscular pathology impairing myogenic responses	
Type 1 or 2 diabetes mellitus	
Taking ototoxic or myorelaxant medication	
Age < 18 yrs	

dB, Decibel; Hz, Hertz.

Germany), tympanometry at 226 Hz (GSI Tympstar Grasonstadler, Eden Prairie, MN, USA), air-conducted and bone-conducted pure-tone liminar audiometry with a TDH 39 headphone and B71 bone vibrator (Equinox, Interacoustics, Middelfart, Denmark), and speech audiometry with french Fournier's disyllabic word lists (Equinox, Interacoustics, Middelfart, Denmark). The last two examinations were performed in a sound-treated audiometric test booth (Boët Stopson, Villeneuve d'Ascq, France). Presbyacusis was not an exclusion criterion.

Recording Procedure of cVEMPs

Participants were seated upright in a soundproof and faradized booth (BERA, Boët StopSon, Villeneuve d'Ascq, France). Electrodes were applied to record the myogenic response (Rosengren et al. 2019). Skin was prepared (Nuprep Skin Prep Gel, Weaver and Company, Colorado, USA and Ether). The active electrode (133 Foam Electrodes, Covidien, Massachusetts, USA) was placed on the middle third of the SCM muscle, ipsilaterally to the sound stimulation. The reference electrode was placed on the manubrium and the ground electrode on the middle of the forehead. The electrode impedance was kept below 5 kΩ and the inter-electrode impedance was below 3 kΩ. Insert earphones (Insert 3M E-A-RTONE 3A, Minneapolis, USA) were put in each ear. The myogenic response record and the sound delivery were carried out via the Eclipse EP25 module (Interacoustics, Assens, Denmark) according to a proper calibration based on the International Organization for Standardization ISO 389-6. Each ear was tested separately via air-conducted sound for recording ipsilateral myogenic responses. Before each sound delivery, the participant's head was turned toward the contralateral side to the sound stimulation and held in this position while recording responses. During the procedure, a control screen of the electromyographic activity was displayed to the participant to give visual feedback of the ipsilateral SCM muscle contraction and to have comparable contractions for the right and the left sides. Electromyography (EMG) activity was monitored from the surface electrodes used to record cVEMPs. The accepted range values of contraction were 50 to 150 µV. Each ear was tested by TBs and NB CE-Chirps at 500 Hz and 1000 HZ at the intensity level of 95 dB nHL. Peak SPLs were 118.5 dB peak SPL for TB 500 Hz, 120.5 dB peak SPL for NB CE-Chirp 500 Hz, 116.5 dB peak SPL for TB 1000 Hz, and 119 dB peak SPL for NB CE-Chirp 1000 Hz. Each TB was delivered for 6 ms (2-2-2 ms rise, fall, and plateau time, respectively) and repeated 200 times for one acquisition. For TBs 500 Hz and 1000 Hz, frequency spectrums respond to the International Electrotechnical Commission IEC 60645-3. NB CE-Chirps durations were pre-defined at 9 ms for 500 Hz (range 360–720 Hz) and at 5 ms for 1000 Hz (range 720–1440 Hz). They were also repeated 200 times for one acquisition. For each subject, equivalent sound energy exposure (L_{Aeq}) was calculated before the start of the study and was 126.96 dB A for 1 second (Colebatch and Rosengren 2014, 2016). On the basis of the optimal parameters reported in the literature (Rosengren et al. 2010, 2019; Papathanasiou et al., 2014; Colebatch et al. 2016), a repetition rate of 5.1/s with a rarefaction polarity and a band-pass filter of 10 to 750 Hz were selected. Electrical activity was recorded from 20 ms before to 80 ms after stimulus onset. For each participant, the initial laterality, as well as the order of the individual tests, was also randomized to exclude a fatigue effect. The variables of interest were the corrected p13-n23 peak to peak amplitudes (CAs) and the p13 (P1) and n23 (N1) latencies (ms).

CA is defined as the ratio of the raw p13–n23 amplitude value recorded during the myogenic reflex divided by the prestimulus contraction value of the SCM muscle (mean rectified EMG). Therefore, the values obtained are no longer dependent on the prestimulus contraction level of the muscle and thus the CA can be compared between the right and left sides. Interaural asymmetry ratios (IAARs) were computed using the following formula: IAAR (%) = 100 × [largest CA (µV) − smallest CA (µV)]/[largest CA (µV) + smallest CA (µV)] (Jongkees et al. 1962). A response was considered to be present only if a biphasic wave was identified at the expected latencies for TBs with a larger amplitude than the recorded noise. P13 and n23 latencies were defined as the positive and the negative polarities of the biphasic wave that appeared at approximately 13 ms and 23 ms, respectively. For NB CE-Chirps, biphasic waves were identified using the same procedure based on the p13 and n23 latencies reported in previous studies (Wang et al. 2014; Ocal et al. 2021). Each recording procedure was repeated twice and the measured values were averaged. The participant was granted one minute's rest between each recording.

Comparison of the Frequency Spectrum of TBs and NB CE-Chirps at the Frequency of 500 Hz

To better understand the findings, the frequency spectrum of the two sound stimuli was analyzed. An ear simulator (type 4157, Brüel & Kjaer, Naerum, Denmark) was connected to one of the insert earphones (IP 30, RadioEar, Middelfart, Denmark). The ear simulator was itself connected to a sound level meter (type 2250, Brüel & Kjaer, Naerum, Denmark) to transform the acoustic signal into an electrical signal. The frequency spectrum can then be displayed on an oscilloscope (type TDS 2004C; Tektronix, Beaverton, Oregon, USA) after a fast Fourier transform.

Statistical Analysis

We analyzed the p13–n23 CA, the p13 and n23 latencies, and the IAARs. Continuous variables were described using means and SDs or medians and interquartile ranges according

TABLE 2. Descriptive data of corrected p13–n23 amplitude, mean rectified EMG, p13 and n23 latencies and IAAR

Stimulus	Tone Burst		NB CE-Chirp	
Frequency	500 Hz	1000 Hz	500 Hz	1000 Hz
CA				
Median (Q1–Q3)	0.97 (0.64–1.47)	0.62 (0.43–0.74)	1.17 (0.78–1.64)	0.56 (0.42–0.66)
Mean rectified EMG (μV)				
Median (Q1–Q3)	96.35 (88.95–115)	97.53 (88.39–112.25)	99.13 (87.55–111.54)	96.45 (86.24–108.10)
p13 latency (ms)				
Median (Q1–Q3)	14.17 (13.50–15.17)	13.84 (13.17–14.50)	11.92 (11.29–13)	11.58 (10.67–12.83)
n23 latency (ms)				
Median (Q1–Q3)	23.67 (22.33–24.67)	22.75 (21.67–23.67)	21.25 (19.67–22.67)	20.42 (19.21–21.50)
IAAR (%)				
Median (Q1–Q3)	8.99 (3.52–18.83)	9.85 (4.45–18.72)	6.39 (2.44–17.17)	10.30 (4.24–15.87)

CA, corrected p13-n23 amplitude; EMG, electromyography; Hz, Hertz; IAAR, interaural asymmetry ratio; ms, millisecond; μV,microvolt; NB CE-Chirp, Narrow band CE-Chirp; Q, quartile.

to the normality of parent distributions. Normality was assessed using QQ plots and Shapiro-Wilk's tests. Comparisons between right and left ears of the same individual were performed using Wilcoxon's signed-rank tests. Continuous variables were compared using nonparametric procedures for paired data (Friedman's tests and Wilcoxon's signed-rank tests), with Dunn-Bonferroni procedures for post hoc multiple comparisons. Correlation analyses were performed using Spearman's correlation coefficients. The rate of responses for the different stimuli was compared by a Cochran's Q test and Bonferroni correction for multiple comparisons. All tests were two-sided with an alpha error level of 0.05. A $p < 0.05$ was considered significant. Statistical analyses were conducted using the software IBM SPSS Statistics version 23.0 (IBM, Ehningen, Germany).

Ethics Approval Statement

Approval for any experiments was obtained from the institutional ethics committee and written informed consent was obtained from all participants for this study.

RESULTS

Left and right ears did not demonstrate any statistical differences for CA, p13 and n23 latencies ($p = 0.121$; $p = 0.266$; $p = 0.312$, respectively; Wilcoxon's signed-rank test). Therefore, the data obtained by both ears were pooled and analyzed individually.

The descriptive data of the studied parameters are reported in Table 2. We observed significant differences for the CA gathered according to the stimulus delivered and its frequency ($p < 0.001$, effect size = 0.721, Friedman's test). NB CE-Chirps 500 Hz produced larger amplitudes than TBs 500 Hz ($p < 0.001$, Dunn-Bonferroni). TBs 500 Hz showed themselves larger CA than NB CE-Chirps 1000 Hz ($p < 0.001$, Dunn-Bonferroni) and TBs 1000 Hz ($p < 0.001$, Dunn-Bonferroni). There was no significant difference between the CA values obtained in TB and NB CE-Chirp at the frequency of 1000 Hz ($p = 0.554$, Dunn-Bonferroni) (Fig. 1).

P13 latencies were significantly affected by the stimulus used ($p < 0.001$, effect size = 0.819, Friedman's test). They were shorter in NB CE-Chirps than in TBs, both at 500 and 1000 Hz ($p < 0.001$, Dunn-Bonferroni) (Fig. 2A). As for n23 latencies,

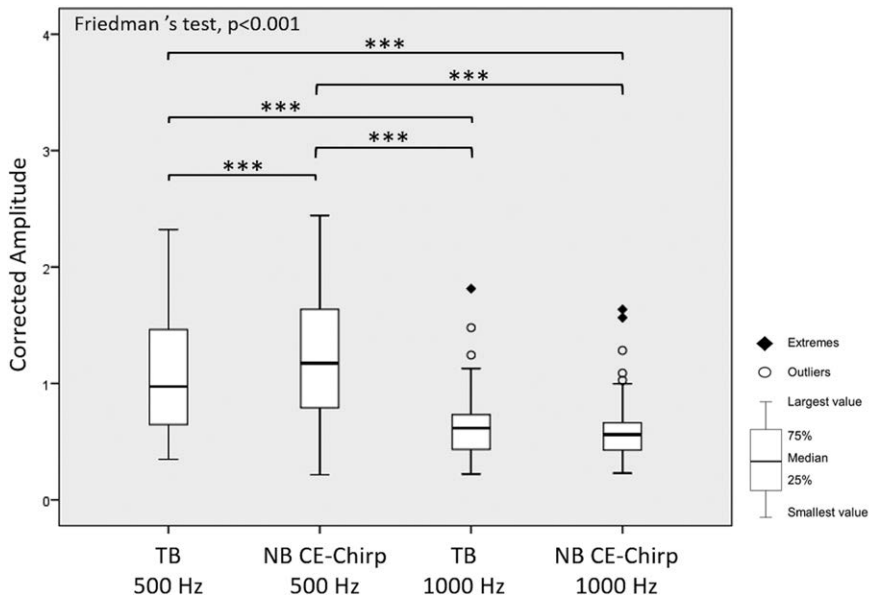

Fig. 1. Boxplots of corrected p13–n23 amplitudes. Corrected p13–n23 amplitudes obtained by sound stimulus (TB versus NB CE-Chirp) and frequency (500 versus 1000 Hz) used for cVEMPs. All pairwise comparisons are topped with * when they are significantly different (Dunn-Bonferroni procedure). Data are presented as boxplots indicating the first and the third quartiles centered on medians (thick lines) with whiskers for the minimum and maximum nonoutlier values, o are outliers, and ♦ show the extreme values. cVEMP, cervical vestibular evoked myogenic potential; Hz, Hertz; NB CE-Chirp, Narrow band CE-Chirp; TB, tone burst.

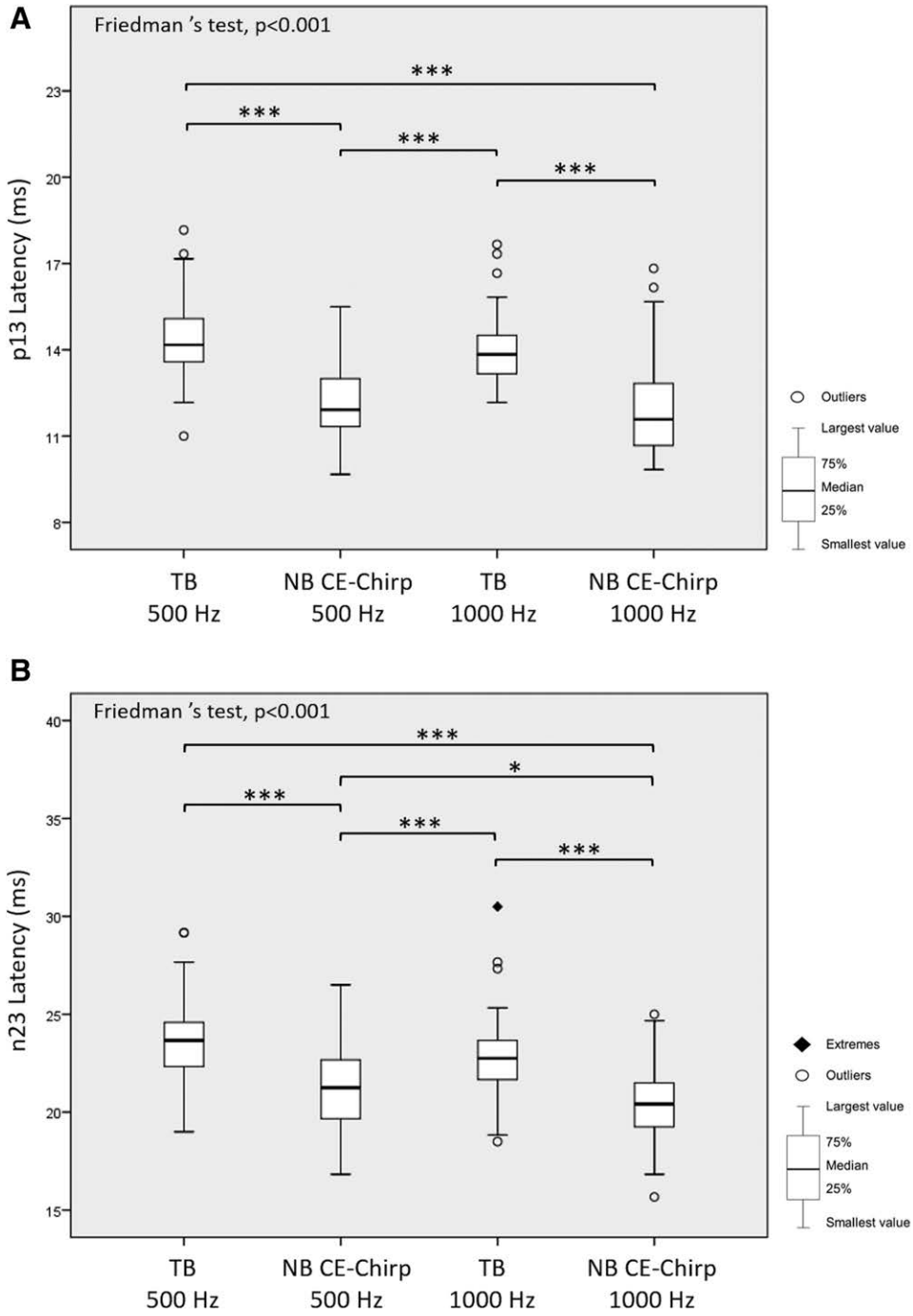

Fig. 2. Boxplots of p13 latency and n23 latency. P13 latency (A) and n23 latency (B) (ms) obtained by sound stimulus (TB versus NB CE-Chirp) and frequency (500 versus 1000 Hz) used for cVEMPs. All pairwise comparisons are topped with * when they are significantly different (Dunn-Bonferroni procedure). Data are presented as boxplots indicating the first and the third quartiles centered on medians (thick lines) with whiskers for the minimum and maximum nonoutlier values, o are outliers, and ◆ show the extreme values. cVEMP, cervical vestibular evoked myogenic potential; Hz, Hertz; ms, millisecond; NB CE-Chirp, Narrow band CE-Chirp; TB, tone burst.

there was also a difference depending on the stimulus and its frequency ($p < 0.001$, effect size = 0.754, Friedman's test). Figure 2B displays decreased n23 latencies for NB CE-Chirp at a 500 and 1000 Hz frequency in comparison with TBs 500 and 1000 Hz ($p < 0.001$, Dunn-Bonferroni). N23 latencies were shorter with NB CE-Chirps 1000 Hz than with NB CE-Chirps 500 Hz ($p = 0.041$, Dunn-Bonferroni).

A negative correlation was observed between the CA and the age of the participants regardless of the stimulus and the frequency studied (Table 3 and Fig. 3A; Spearman's rank correlation coefficient). The p13 and n23 latencies were not correlated with the age of the subjects (Table 3 and Figs. 3B, C); Spearman's rank correlation coefficient).

IAARs did not change significantly according to the stimulus and the chosen frequency ($p = 0.886$, Friedman's test).

Finally, all the volunteers were distributed into three age groups (by age group of 18 years) and we compared the rates of elicited responses according to the stimulus and the frequency

TABLE 3. Representative data of Spearman's correlation test for corrected p13–n23 amplitudes, p13 and n23 latencies according to the age of the participants

		Experimental Conditions			
Correlation		Tone Burst (500 Hz)	Tone Burst (1000 Hz)	NB CE-Chirp (500 Hz)	NB CE-Chirp (1000 Hz)
Age-CA	*r*	–0.482	–0.370	–0.545	–0.466
	p	<0.001	0.004	<0.001	<0.001
Age-p13 latency	*r*	–0.167	–0.090	0.012	–0.068
	p	0.205	0.500	0.927	0.604
Age-n23 latency	*r*	–0.073	–0.175	–0.042	–0.196
	p	0.581	0.190	0.745	0.134

CA, corrected p13–n23 amplitude; Hz, Hertz; NB CE-Chirp, Narrow band CE-Chirp; R, Spearman's correlation coefficient.

delivered. The results are presented in Table 4. In group 3 (56–74 years), NB CE-Chirps 500 and 1000 Hz had significantly higher response rates than TBs 500 Hz ($p = 0.039$, Cochran's Q test and Dunn-Bonferroni).

DISCUSSION

CVEMPs were first described in 1994 (Colebatch et al. 1994). They were initially triggered by clicks like auditory-evoked potentials (AEPs) (Colebatch et al. 1994). Later, through larger amplitudes obtained at lower stimuli intensities and a better response rate, air-conducted 500 Hz TBs replaced clicks to generate cVEMPs (Murofushi et al. 1999; Todd et al. 2000; Welgampola and Colebatch 2001a; Akin et al. 2003; Viciana and Lopez-Escamez 2012). The better frequency selectivity of 500 Hz TBs and its longer duration could explain the better results (Viciana and Lopez-Escamez 2012). However, even with TBs, the muscle reflex can be more often absent in individuals over 50 to 60 years with no history of dizziness or neuromuscular disorder (Rosengren et al. 2011; Piker et al. 2015). NB CE-Chirps were developed from Chirps to improve the detection of hearing thresholds in AEPs and auditory steady-state responses (ASSRs). Recently, this stimulus was reported to provide larger n1–p1 amplitudes in oVEMPs than with TBs at a frequency of 500 Hz by air conduction in healthy subjects (Mat et al. 2021). Two other studies confirmed this observation on oVEMPs by bone and air conduction at 500 Hz (Karaçaylı et al. 2020; Çoban et al. 2021). Regarding cVEMPs, the advantage of using NB CE-Chirps over TBs is unclear. Indeed, a first study compared the p13-n23 amplitude values obtained when cVEMPs were generated by clicks, air-conducted 500 Hz tone pips, or air-conducted 500 Hz NB CE-Chirps in a group of healthy subjects (Wang et al. 2014). NB CE-Chirps showed higher amplitudes (Wang et al. 2014). A second study analyzed the amplitude values recorded with 500 Hz air-conducted TBs and NB CE-chirps in a group of healthy volunteers (Ocal et al. 2021). This time, no difference was observed (Ocal et al. 2021). But, although the mean rectified EMG appears to have been measured, the raw amplitudes were compared and not the CA. However, it has been shown that the more the SCM muscle is contracted, the more the raw amplitude of the cVEMP increases (Colebatch et al. 1994). This linear relationship is applicable up to a certain level of contraction from which the raw amplitudes no longer increase and therefore decrease the CA values (Bogle et al. 2013). This lack of amplitude correction could explain the lack of significance observed.

In the presented study, the CA values were significantly larger when the stimulation frequency was 500 Hz in TB and in NB CE-Chirp compared with the 1000 Hz frequency. This result is probably explained by the resonance frequency of the middle ear-vestibular system which is also around 500 Hz in a healthy young or middle-aged individual (Park et al. 2010; Colebatch et al. 2016). It is interesting that the greatest CA values were registered with NB CE-Chirps 500 Hz. Better frequency specificity of NB CE-Chirps compared with TBs could be the underlying mechanism as in ASSRs or AEPs (Johnson and Brown 2005; Harte et al. 2007; Ferm et al. 2013; Ferm and Lightfoot 2015). Regarding raw amplitudes values, we observed the same results than with the CA. In our study, the level of SCM muscle contraction was similar regardless of the stimulation parameter used (Table 2). Unfortunately, prestimulus muscle activity values are not reported by Ocal et al. (2021).

Besides, two other kinds of NB Chirps have been assessed in cVEMPs and guided us to this assumption (Özgür et al. 2015; Walther and Cebulla 2016). Walther and Cebulla compared the amplitudes obtained in oVEMPs and cVEMPs when the stimulus was a click, a TB 500 Hz, or a Cebulla Walther-VEMP-Chirp (CW-VEMP-Chirp). This last stimulus is a Narrow band chirp especially designed for VEMPs with a frequency range of 250 to 1000 Hz in air conduction (Walther and Cebulla 2016). The highest amplitudes were observed with CW-VEMP-Chirp which agrees with our results. The other study compared the cVEMPs responses obtained with these same types of stimuli presented by air conduction (Özgür et al. 2015). In this case, the NB Chirps revealed the lowest amplitudes. The large range of frequency content of these NB Chirps (500–4000 Hz) as well as the position of the stimulus (not quite centered on 500 Hz frequency) might explain these results. These observations highlight the great importance of using a stimulus of a narrow range of frequency and centered on 500 Hz. To compare the frequency selectivity of NB CE-Chirp and TB 500 Hz, we performed a spectral analysis of these two acoustic stimuli. Figure 4 shows that the frequency spectrum of TB contains three energy lobes. The main lobe is centered at 500 Hz and the side lobes are located at lower and higher frequencies. These side lobes are too low in energy and too far in frequency and constitute spectral splatter (Johnson and Brown 2005; Harte et al. 2007; Ferm et al. 2013; Ferm and Lightfoot 2015). NB CE-Chirp 500 Hz does not display spectral splatter phenomenon. We can also see that its extremes correspond better to the optimum frequencies to elicit cVEMPs and thus that NB CE-Chirp 500 Hz has better frequency specificity than TB 500 Hz (Murofushi et al. 1999; Todd et al. 2000; Welgampola and Colebatch 2001a; Akin et al. 2003). Indeed, frequency tuning of

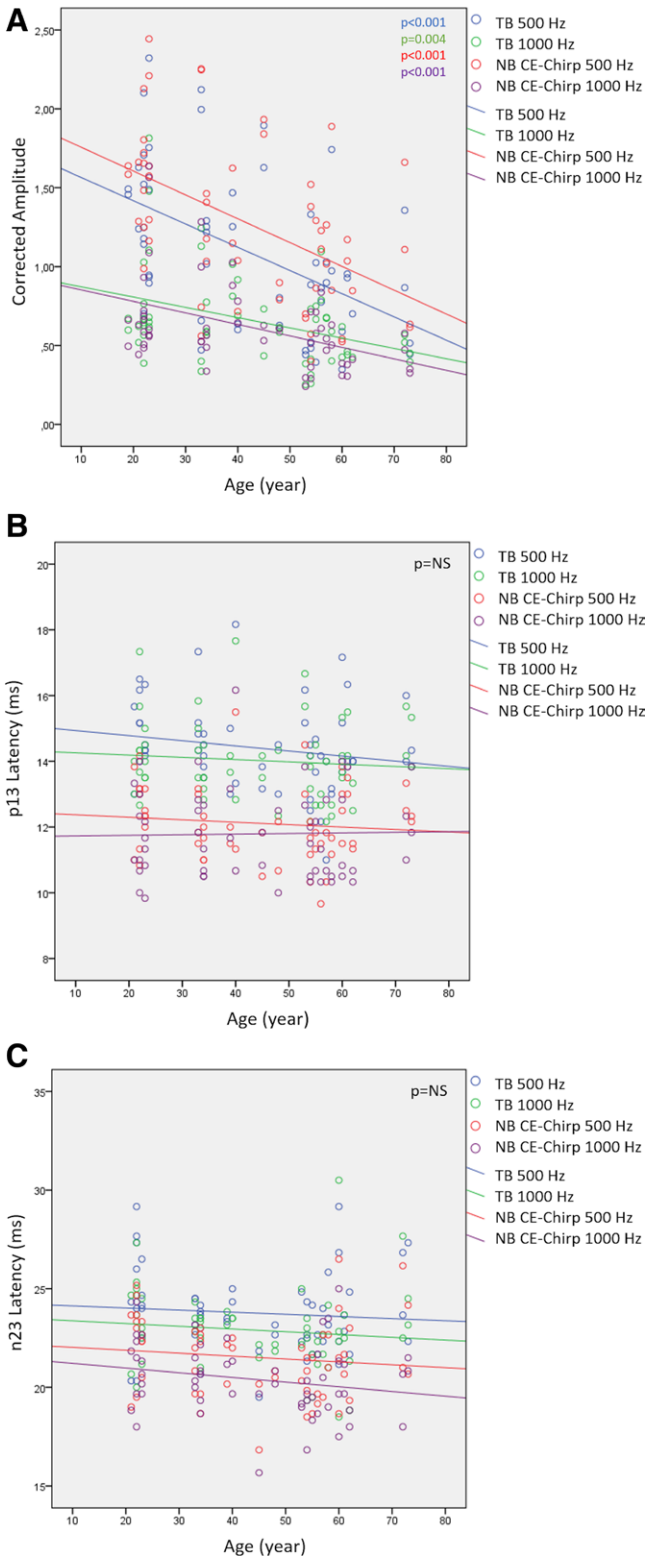

Fig. 3. Correlation between the age and the corrected p13–n23 amplitude, the p13 and n23 latencies. Scatter plot of Spearman correlation coefficient between the age (yrs) and the corrected p13–n23 amplitude (A), the p13 (B), and n23 (C) latency (ms) in TB 500 Hz (blue slope), TB 1000 Hz (green slope), NB CE-Chirp 500 Hz (red slope) and NB CE-Chirp 1000 Hz (purple slope) for cVEMPs. cVEMP, cervical vestibular evoked myogenic potential; Hz, Hertz; ms,millisecond; NB CE-Chirp, Narrow band CE-Chirp; NS, non-significant; TB, tone burst.

TABLE 4. Response rates obtained according to the stimulus and the frequency delivered among three age groups

	500 Hz		1000 Hz	
Frequency Stimulus	Tone Burst (%)	NB CE-Chirp (%)	Tone Burst (%)	NB CE-Chirp (%)
Group 1 (18–36 yrs), N = 28 ears	100	100	89.3	92.9
Group 2 (37–55 yrs), N = 16 ears	100	100	100	100
Group 3 (56–74 yrs), N = 18 ears	83.3	100	94.4	100
Total, N = 62 ears	95.2	100	93.5	96.8

Hz, Hertz; NB CE-Chirp, Narrow band CE-Chirp.

the cVEMPs is located around 400 to 1000 Hz (Murofushi et al. 1999; Todd et al. 2000; Welgampola and Colebatch 2001a; Akin et al. 2003). In addition, part of the energy of the NB CE-Chirp 500 Hz is distributed over frequencies close to 1000 Hz. This configuration could explain the better response rates observed with this stimulus (100%) in group 3 (56–74 years) compared with the TB 500 Hz (83.3%). Indeed, a frequency tuning to 1000 Hz was described in TB for older people (Taylor et al. 2012; Piker et al. 2013). It, therefore, does not seem necessary to change the stimulation frequency to 1000 Hz in elderly to elicit cVEMPs with NB CE-Chirps. This is the first study assessing the cVEMPs responses obtained with NB CE-Chirps on the elderly and at a frequency of 1000 Hz. Although the better response rate observed with NB CE-Chirps 500 and 1000

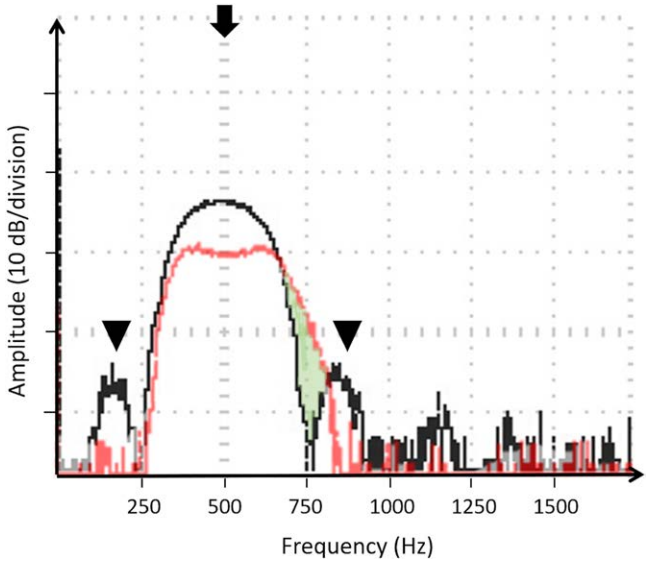

Fig. 4. Comparison of frequency spectra of TB and NB CE-Chirp at the frequency of 500 Hz. The frequency spectrum of TB (black) is composed of three energy lobes. The main lobe is centered on 500 Hz (vertical arrow) and the side lobes are located at lower and higher frequencies. The frequency spectrum of NB CE-Chirp (red) is also centered on 500 Hz (vertical arrow). The green area represents the part of the energy of NB CE-Chirp 500 Hz that is distributed at higher frequencies than TB 500 Hz, close to 1000 Hz. The x-axis represents the set of frequencies (Hz) over which each of the stimuli is distributed. The y-axis represents the distribution of intensities (dB) of each stimulus. ▼point to side lobes. dB, Decibel; Hz, Hertz; NB CE-Chirp, Narrow band CE-Chirp; nHL, normalized HL; TB, tone burst.

Hz seems to reduce the number of falsely absent responses in a healthy population, it would be interesting to assess in further studies if NB CE-Chirps can identify a saccular disorder with the same precision as TBs.

Regarding p13 and n23 latencies, they were significantly shortened with the NB CE-Chirps whatever the frequency. It has already been reported in cVEMPs and oVEMPs. It is probably induced by the presentation time of NB CE-Chirps which is always earlier than for TBs (Wang et al. 2014; Karaçaylı et al. 2020; Çoban et al. 2021; Mat et al. 2021; Ocal et al. 2021). It has also been suggested that primary vestibular neurons may have double or triple firing to one TB and the latencies of VEMPs responses might be delayed to this second or third spikes, unlike NB CE-Chirps (Cheng and Murofushi 2001a).

In addition, we noted shorter n23 latencies with NB CE-Chirps 1000 Hz compared with NB CE-Chirps 500 Hz. The shorter duration and rise time of NB CE-Chirps 1000 Hz might justify this result (Cheng and Murofushi 2001b; Burgess et al. 2013).

Because the influence of the age of the participants on the amplitude values has never been assessed in cVEMPs with NB CE-Chirps, we carried out correlation tests for the four sound stimulations delivered. We observed a negative correlation between the participant's age and the recorded amplitude values in the four conditions. Degeneration of terminal vestibular organs and their differences could be the underlying phenomenon (Welgampola and Colebatch 2001b; Basta et al. 2005; Walther and Westhofen 2007; Colebatch et al. 2013). A decrease in cervical muscle tonicity with aging was not observed previously and would appear to be less likely (Basta et al. 2005, 2007; Lee et al. 2008). As for the p13 and n23 latencies, they do not seem to be affected by the age of the volunteers (Basta et al. 2005; Tourtillott et al. 2010).

Finally, reducing the IAARs by the best frequency specificity of the NB CE-Chirps was conceivable. We did not observe any differences for IAARs according to the stimulus delivered. The median values are in agreement with previous works on cVEMPs (Welgampola and Colebatch 2001b; McCaslin et al. 2014).

CONCLUSIONS

cVEMPs are short-latency myogenic reflexes for which obtaining reliable waveforms of potentials remains particularly challenging, especially in elderly. NB CE-Chirps 500 Hz improved the corrected p13-n23 amplitudes recorded in a group of healthy subjects, as a result of better frequency specificity than with TBs. This would increase the investigator's confidence in the wave's detection and reduce the number of falsely absent responses in a healthy population. A better response rate was shown with NB CE-Chirps compared with TBs in older people at a frequency of 500 Hz. It does not seem necessary to perform cVEMPs at a frequency of 1000 Hz in the elderly group with NB CE-Chirps. cVEMPs amplitudes and age were negatively correlated whatever the stimulus and frequency used. Further studies in a large cohort of healthy subjects and selected patients with a vestibular disorder are warranted.

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