



Optimizing Auditory Brainstem Response Test with Narrow Band Level-Specific CE-Chirps

Nilüfer Bal^{1,✉} Özge Gedik Toker^{1,✉} Hilal Hüsam^{1,✉} Sümeyye Özdemir^{1,✉} Bartłomiej Dao Lien^{2,3,✉}

¹Department of Audiology, Faculty of Health Sciences, Bezmialem Vakıf University, Istanbul, Turkey

²Audiology Amplifon, Warsaw, Poland

³Instytut Pomnik - Centrum Zdrowia Dziecka, Warsaw, Poland

Address for correspondence Hilal Hüsam, MSc, Department of Audiology, Faculty of Health Sciences, Bezmialem Vakıf University, Eyüp Sultan, İstanbul, 34050, Turkey (e-mail: hhusam@bezmialem.edu.tr)

Ann Otol Neurotol ISO 2022;5:50–54.

Abstract

Objective The aim of the study was to evaluate the effects of narrow band level-specific Claus Elberling-Chirp (NB LS CE-Chirp) and LS CE-Chirp stimuli on the amplitudes, latencies, and interpeak latencies in comparison with tone burst (TB) and click.

Methods A total of 40 ears (10 males, 10 females; age range: 20–26) individuals who had no complaints related to hearing participated in the study. Differences between click and LS CE-Chirp, frequency-specific (500–1,000–2,000–4,000) TB, and NB LS CE-Chirp were investigated at stimuli intensity of 70 decibel normal hearing loss (dBnHL).

Results Absolute latencies were obtained longer in LS CE-Chirp than click stimulus, except wave V. At all frequencies, absolute latencies of I-III-V waves obtained with TB were significantly longer than those obtained with NB LS CE-Chirp. Amplitudes were higher in NB LS CE-Chirp compared to click and TB at all frequencies except 500 Hz.

Conclusion The use of NB LS CE-Chirp is advantageous in patient assessment, but the benefit decreases at low frequencies. The differences in latency values of the stimuli should be taken into account in order to make a reliable interpretation of the results.

Keywords

- tone burst
- chirp
- auditory evoked potential
- click

Introduction

The auditory brainstem response (ABR) is an auditory-evoked potential obtained by recording neural activation in the auditory nerve, auditory tract, and nuclei in the brainstem^{1,2} in the first 10 ms after stimulus delivery. The ABR test can be used to assess the integrity of the auditory nervous system and to investigate the presence of cochlear and retrocochlear pathologies.^{1,3} Absolute latency, amplitude, and inter-wave latency of the first five waves formed in the ABR recording are evaluated. Considered to be an objective test and have high diagnostic value, ABR test has found wide use in clinics.

Different types of stimuli can be used in the ABR test to assess the neural integrity. Click stimulus has been widely used for many years because of its sudden onset and short duration (100 μ s). In the click stimulus, the sound wave encounters a temporal delay as it is transmitted across the basilar membrane, and the high-frequency region is excited before the low-frequency region. As a result, a less synchronized neural activity occurs, particularly between 2 and 4 kHz. Although the click stimulus gives information about the cochlea, it does not provide frequency-specific information.³

DOI <https://doi.org/10.1055/s-0043-1764180>
ISSN 2581-9607

© 2023. Indian Society of Otolaryngology.

This is an open access article published by Thieme under the terms of the Creative Commons Attribution-NonDerivative-NonCommercial-License, permitting copying and reproduction so long as the original work is given appropriate credit. Contents may not be used for commercial purposes, or adapted, remixed, transformed or built upon. (<https://creativecommons.org/licenses/by-nc-nd/4.0/>).

Thieme Medical and Scientific Publishers Pvt. Ltd. A-12, 2nd Floor, Sector 2, Noida-201301 UP, India

Another stimulus, tone burst (TB), is a short duration stimulus used to determine the frequency-specific thresholds. However, it is reported that the frequency specificity of the response may be low, especially at low frequencies, since TB excites other regions of the cochlea apart from the targeted frequency region.⁴

Chirp stimulus was developed to increase the synchronization among neurons. The design of the chirp stimulus is that the low frequency component is presented first, followed by the mid- and high-frequency components of the stimulus, to rule out the time delay that occurs when the stimulus reaches the apex of the cochlea. Therefore, low- and high-frequency stimuli reach the cochlea at the same time, causing the nerve fibers to fire simultaneously in a synchronized manner.^{5,6}

Recently, Elberling and Don developed a level-specific chirp (LS Chirp) stimulus in order to determine the neural response more clearly and easily by using different delay times at different frequencies depending on the intensity of the stimulus.⁷

ABR test results are evaluated by analyzing the latency and the amplitude of the waves obtained. When different stimuli such as click, TB, LS CE (Claus Elberling)-Chirp are used, these analysis values differ for each stimulus. Studies in the literature mostly focused on click and TB stimuli. For this, the purpose of this study is to reveal the differences in the waves obtained in click and TB stimuli for the 70 decibel normal hearing loss (dBnHL) intensity level, which is frequently used in site of lesion evaluation, with the LS CE-Chirp, a new stimulus with more effective synchronization. Determining these differences is thought to increase the accuracy of ABR test results.

Materials and Methods

This prospective study was conducted in the Audiology Clinic of Bezmialem Vakif University. The study was approved by the ethics committee of our university with the decision number "19/367" on 25.10.2019 and was carried out in accordance with the ethical principles stated in the "Declaration of Helsinki." Participants were informed about the procedure to be applied, and they approved their participation in the study by signing the voluntary consent form. A total of 20 volunteers (40 ears), 10 male (20 ears), and 10 female (20 ears) aged between 20 and 26 years, were included in the study group. All ears were included in the study as there was no difference found between the right and left ears.

For the audiological evaluation of the participants, the hearing threshold was evaluated using the Otometrics Madsen Astera (GN Otometrics A/S, Hoerskaetten 9, Taastrup, DK-2630, Denmark) clinical audiometer. Air conduction hearing thresholds with TDH-39 standard earphones at octave frequencies between 250 and 8,000 Hz and bone conduction hearing thresholds with B-71 vibrator at octave frequencies between 500 and 4,000 Hz were evaluated. The tympanometric evaluation was performed with Interacoustic Titan (Interacoustics A/S, Audiometer Allé 1, 5500 Middelfart, Denmark) immittance at 226 Hz probe tone.

In pure tone audiometry, at frequencies of 250 to 8,000 Hz, the individuals who have pure tone thresholds

between -10 and 15 dB at octave frequencies between 250 and 8,000 Hz, normal tympanogram (type A), and without neurological and metabolic disease were included in the study.

ABR test was performed using Interacoustics Eclipse EP25 (Interacoustics A/S, Audiometer Allé 1, 5500 Middelfart, Denmark) device using Ambu Neuroline 720 disposable superficial electrodes. Before electrode placement, the areas of the participants where electrodes will be placed were cleaned with Nuprep gel. The positive electrode was placed on the upper forehead region (Fpz), the ground electrode was placed under the positive electrode, and the negative electrodes were placed one on the left earlobe and the other on the right earlobe to prevent postauricular muscle artifact. Attention was paid to ensure that the electrode impedances were below 5 k Ω and that the inter-electrode impedance was no more than 2 k Ω . ER-3A insert earphones were used to deliver the acoustic stimuli. The ABR test was performed in quiet test room, with the lights off, in a relaxed supine position and/or natural sleep for all participants.

Click and LS CE-Chirp threshold stimuli were delivered monaurally for both ears to all participants. TB and LS CE-Chirp stimuli at frequencies of 500–1,000–2,000–4,000 Hz were used for frequency-specific recordings. For all recordings, the intensity level was determined as 70 dBnHL, alternate polarity, rate 27.1/s, band pass filter 1,500–33 Hz 6/octave, artifact rejection level $\pm$ 40 μ V, and time window 20 ms. Recording was interrupted when the number of sweeps for each stimulus was at least 3,000 and waveform was clearly observed. Two traces were obtained for each recording to ensure the wave reproducibility. Absolute latencies and amplitudes of waves I, III, and V, and latency values between waves I to III, III to V, and I to V were determined by an experienced audiologist.

Obtained data were analyzed with IBM SPSS 20.0 program. When comparing the two stimuli, the *t*-test and Wilcoxon test were used between groups, and the significance of the difference between the means for parameters with more than two measurements was examined using the analysis of variance and Friedman tests in repeated measures. A *p*-value of less than 0.05 was accepted as a significant difference.

Results

A statistical evaluation was made from the results obtained for both ears in all stimuli. Since there was no significant difference between the ears, a total of 40 ears were included in the study. The average age of the participants in the study was 22.3 ± 1.65 (20–26 years old). Ten females and 10 males participated in the study and the number of females and the males was kept equal in order to exclude the effect of gender on the results.

Wave I and III absolute latencies were significantly longer for LS CE-Chirp than click ($p < 0.001$, $p = 0.010$, respectively), and absolute latency values of wave V were shorter ($p = 0.003$). Wave I, III, and V amplitude values were obtained significantly larger for LS CE-Chirp ($p < 0.001$). Interpeak latencies for all waves were significantly shorter in LS CE-Chirp stimulus ($p < 0.001$; –Table 1).

In the frequency-specific ABR assessment, complete I-III-V waves could not be obtained from all participants at frequencies of 500 and 1,000 Hz. Wave I was observed only in 4 ears (10%) and wave III in 12 ears (30%) for 500 Hz narrow band (NB) LS CE-Chirp. For 500 Hz TB, wave I was recorded only in 2 ears (5%) and wave III in 4 ears (10%).

Wave I was detected in 21 ears (53%), wave III in 28 ears (70%) for 1,000 Hz NB LS CE-Chirp stimulus, whereas these values were in 16 ears (40%) and wave III in 19 ears (48%) for TB.

In the comparison of 500 and 1,000 Hz's waves, 1,000 Hz NB LS CE-Chirp had V wave amplitude significantly larger ($p < 0.001$). The absolute latency of the V wave obtained with 500 and 1,000 Hz NB LS CE-Chirp stimulus was significantly shorter than the TB stimulus ($p < 0.001$; ►Table 2).

Absolute latency of wave I, III, and V observed at 2,000 and 4,000 Hz NB LS CE-Chirp was significantly shorter than

the TB ($p < 0.05$). While the mean amplitude of I, III, and V in 2,000 Hz NB LS CE-Chirp and wave I, V in 4,000 Hz NB LS CE-Chirp stimulus was larger, the difference was only significant for wave V amplitude at 4,000 Hz ($p < 0.001$; ►Table 2).

Interpeak latencies could only be evaluated at 2,000 and 4,000 Hz. The interpeak latencies of I to III, III to V, I to V obtained with the 2,000 and 4,000 Hz NB LS CE-Chirp were significantly shorter than the TB ($p < 0.05$; ►Table 3).

When the absolute latencies were compared among all stimuli, where waves I, III, and V were obtained; latency of waves I and III was the longest with 2,000 Hz TB and latency of wave V was the longest with 500 Hz TB.

When the mean amplitude is compared among all stimuli from which I, III, and V waves were obtained, the largest amplitude was obtained in LS CE-Chirp stimulus for all waves. When V/I amplitude ratios were compared between

Table 1 The mean latency and amplitude values of LS CE-Chirp and click ($ap < 0.05$)

		Waves	LS CE-Chirp	Click	
			Mean $\pm$ SD	Mean $\pm$ SD	p-Value
Latency (ms)	I		1.82 $\pm$ 0.17	1.64 $\pm$ 0.14	< 0.001 ^a
	III		3.85 $\pm$ 0.20	3.79 $\pm$ 0.18	0.009 ^a
	V		5.49 $\pm$ 0.30	5.60 $\pm$ 0.29	0.003 ^a
Amplitude (μ V)	I		0.25 $\pm$ 0.15	0.19 $\pm$ 0.13	0.001 ^a
	III		0.21 $\pm$ 0.11	0.16 $\pm$ 0.10	0.006 ^a
	V		0.68 $\pm$ 0.23	0.46 $\pm$ 0.15	< 0.001 ^a
Interpeak latencies (ms)	I-III		2.03 $\pm$ 0.09	2.15 $\pm$ 0.11	< 0.001 ^a
	III-V		1.63 $\pm$ 0.18	1.82 $\pm$ 0.18	< 0.001 ^a
	I-V		3.66 $\pm$ 0.22	3.97 $\pm$ 0.21	< 0.001 ^a

Abbreviations: CE, Claus Elberling; LS, level specific; ms, millisecond; μ V, microvolt; SD, standard deviation.

Table 2 The mean latency and amplitude values of NB LS CE-Chirp and tone burst ($ap < 0.05$)

		Waves	NB LS CE-Chirp	Tone burst	
			Mean $\pm$ SD	Mean $\pm$ SD	p-Value
500 Hz	Latency (ms)	V	5.72 $\pm$ 0.54	9.51 $\pm$ 0.58	< 0.001 ^a
	Amplitude (μ V)	V	0.26 $\pm$ 0.14	0.31 $\pm$ 0.14	0.070
1,000 Hz	Latency (ms)	V	5.97 $\pm$ 0.49	7.87 $\pm$ 0.54	< 0.001 ^a
	Amplitude (μ V)	V	0.43 $\pm$ 0.13	0.33 $\pm$ 0.14	< 0.001 ^a
2,000 Hz	Latency (ms)	I	2.25 $\pm$ 0.22	2.79 $\pm$ 0.22	< 0.001 ^a
		III	4.25 $\pm$ 0.23	4.87 $\pm$ 0.30	< 0.001 ^a
		V	5.81 $\pm$ 0.42	6.70 $\pm$ 0.37	< 0.001 ^a
	Amplitude (μ V)	I	0.12 $\pm$ 0.06	0.11 $\pm$ 0.07	0.292
		III	0.15 $\pm$ 0.07	0.14 $\pm$ 0.09	0.381
		V	0.38 $\pm$ 0.13	0.34 $\pm$ 0.13	0.175
4,000 Hz	Latency (ms)	I	2.00 $\pm$ 0.26	2.11 $\pm$ 0.13	0.006 ^a
		III	4.03 $\pm$ 0.27	4.22 $\pm$ 0.19	< 0.001 ^a
		V	5.74 $\pm$ 0.25	6.06 $\pm$ 0.24	< 0.001 ^a
	Amplitude (μ V)	I	0.22 $\pm$ 0.11	0.21 $\pm$ 0.09	0.798
		III	0.14 $\pm$ 0.07	0.16 $\pm$ 0.08	0.269
		V	0.44 $\pm$ 0.12	0.36 $\pm$ 0.12	< 0.001 ^a

Abbreviations: CE, Claus Elberling; Hz, Hertz; LS, level specific; ms, millisecond; μ V, microvolt; NB, narrow band; SD, standard deviation.

Table 3 Interpeak latencies of NB LS CE-Chirp and tone burst stimuli ($p < 0.05$)

		Waves	NB LS CE-Chirp	Tone burst	
			Mean $\pm$ SD	Mean $\pm$ SD	<i>p</i> -Value
2,000 Hz	Latency (ms)	I–III	1.99 $\pm$ 0.16	2.08 $\pm$ 0.19	0.017 ^a
		III–V	1.57 $\pm$ 0.24	1.84 $\pm$ 0.18	< 0.001 ^a
		I–V	3.55 $\pm$ 0.31	4.01 $\pm$ 0.58	< 0.001 ^a
4,000 Hz	Latency (ms)	I–III	2.03 $\pm$ 0.12	2.10 $\pm$ 0.13	0.006 ^a
		III–V	1.71 $\pm$ 0.26	1.84 $\pm$ 0.20	0.012 ^a
		I–V	3.75 $\pm$ 0.27	3.95 $\pm$ 0.20	< 0.001 ^a

Abbreviations: CE, Claus Elberling; Hz, Hertz; LS, level specific; ms, millisecond; μ V, microvolt; NB, narrow band; SD, standard deviation.

LS CE-Chirp and click, the mean value and standard deviation for LS CE-Chirp and click were 4.55 ± 4.29 and 3.70 ± 3.56 , respectively. No significant difference was observed between the two stimuli.

Discussion

In our study, the changes in the waves obtained in 40 ears with normal hearing by using click, LS CE-Chirp, TB and NB LS CE-Chirp stimuli were investigated.

Latencies of waves I and III were significantly longer and the wave V latency was shorter in the LS CE-Chirp than click stimulus. Similarly, Cargnelutti et al⁸ reported the same mean absolute latency values of waves I and III between stimuli at 85 dBnHL, while the wave V absolute latency was shorter in LS CE-Chirp stimulus. This delay in I and III waves is thought to be due to the longer duration of the LS CE-Chirp stimulus compared to the click stimulus.

Regarding amplitude of wave V; Cargnelutti et al⁸ and Kristensen and Elberling⁹ reported significantly larger amplitudes in NB LS CE-Chirp stimulus (85 and 80 dBnHL, respectively). Kristensen and Elberling did not report a significant difference in lower intensities (60, 40, 20 dBnHL) in their study.⁹ In our study, wave I, III, and V amplitudes were obtained significantly larger in NB LS CE-Chirp stimulus at 70 dBnHL. The chirp stimulus is designed to compensate for the cochlear traveling wave delay. Transmitting the low frequency component before the high frequency component provides synchronized stimulation and as a result, larger amplitude responses recorded. According to the results of our study, the advantage of NB LS CE-Chirp is not only valid for the wave V but also for the other waves and its advantage becomes more evident than the click stimulus from the intensity level of 70 dBnHL and above.

In studies comparing the latency of frequency-specific stimuli, the latency of the TB stimulus was found to be significantly longer than chirp at all frequencies, similar to our study.^{10,11} It is well known that this difference in latencies is due to the design of the stimulus. Since the onset of NB LS CE-Chirp stimulus is earlier than TB, the latency of NB LS CE-Chirp stimulus is shorter than the latency of the TB stimulus.^{10,11}

In our study, the amplitude of the wave V at all frequencies, except 500 Hz, was higher in the LS CE-Chirp stimulus. Similarly, studies in the literature have reported

the low amplitude for NB LS CE-Chirp than TB stimulus at 500 Hz.^{10–12} It has been stated that the maximum synchronization at 500 Hz is 30 dBnHL and when this level is exceeded, the amplitude advantage of the chirp stimulus decreases compared to other frequencies.¹² In addition, since TB and chirp stimulus spectra are similar at 500 Hz compared to other frequencies, the number of neuron fibers stimulated is close to each other. Therefore, the amplitude advantage of the chirp stimulus for 500 Hz is reduced compared to other frequencies.¹¹ It has been reported that the wave V amplitude at 1,000, 2,000, and 4,000 Hz was greater in the NB LS CE-Chirp stimulus.^{10,12–14} The reason for that is the increased synchronization due to the design of the NB LS CE-Chirp stimulus mentioned above.¹³

When comparing all stimuli, wave I, III, and V mean amplitude was the highest in LS CE-Chirp stimulus, suggestive of the synchronized design of LS CE-Chirp is effective. Additionally, V/I ratio was higher for LS CE-Chirp than click; however, the difference was not significant. As a result, it is thought that the use of LS CE-Chirp stimulus might be more valuable in determining ABR waves.

The differences between the results obtained in the studies in the literature where different stimuli were compared may be due to the environmental conditions in which the ABR test was performed, the model and calibration of the device used, and the differences in the recording parameters. In the literature, usually CE-Chirp stimulus was used in studies in populations with different ages and diseases. However, few studies have used the level-specific stimulus, which is NB LS CE-Chirp.¹⁵ Megha et al¹⁵ reported that NB stimulus is promising in noise-induced hearing loss and evaluation of cochlear synaptopathy. However, they only evaluated the absolute latency and amplitude values of wave V. The absolute latencies and amplitudes of wave I and wave III values in normal hearing subjects will contribute to the literature.

We believe that our study, together with the three main wave components (I, III, and V) obtained in the ABR test, will be useful in filling the gap on the comparison of frequency-specific TB and LS CE-Chirp stimuli in the literature. In addition, it was observed that the LS CE-Chirp was more advantageous in terms of amplitude at 70 dBnHL intensity, which is frequently used in site of lesion evaluation. It is thought that these results are informational for pathological and nonpathological evaluations for future studies.

The limitation of our study is lack of investigation of the differences between stimuli at several intensity levels and various types of hearing impairments. Future studies establishing the differences between the stimuli and intensity level will contribute to lesion location and patient evaluation studies.

Conclusion

The stimuli-related changes may cause the clinician to misinterpret the results obtained with ABR test. Therefore, differences depending on the type of stimulus should be considered in patient evaluation.

Funding

None.

Conflict of Interest

None declared.

References

- 1 Hecox K, Galambos R. Brain stem auditory evoked responses in human infants and adults. *Arch Otolaryngol* 1974;99(1):30–33
- 2 Picton TW. *Human Auditory Evoked Potentials*. San Diego, CA: Plural Publishing; 2019: 213–247
- 3 Hall JW. *New Handbook of Auditory Evoked Responses*. Boston, MA: Pearson; 2007:11–17
- 4 Hall JW. *eHandbook of Auditory Evoked Responses*. Seattle, WA: Kindle Direct Publishing; 2015
- 5 Cebulla M, Stürzebecher E, Elberling C, Müller J. New click-like stimuli for hearing testing. *J Am Acad Audiol* 2007; 18(9):725–738
- 6 Elberling C, Don M. Auditory brainstem responses to a chirp stimulus designed from derived-band latencies in normal-hearing subjects. *J Acoust Soc Am* 2008;124(5):3022–3037
- 7 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(5):2955–2964
- 8 Cargnelutti M, Cóser PL, Biaggio EPV. LS CE-Chirp® vs. Click in the neuroaudiological diagnosis by ABR. *Rev Bras Otorrinolaringol (Engl Ed)* 2017;83(3):313–317
- 9 Kristensen SG, Elberling C. Auditory brainstem responses to level-specific chirps in normal-hearing adults. *J Am Acad Audiol* 2012;23(9):712–721
- 10 Dzulkarnain AAA, Abdullah SA, Ruzai MAM, Ibrahim SHMN, Anuar NFA, Rahim EA. Effects of different electrode configurations on the narrow band level-specific CE-Chirp and tone-burst auditory brainstem response at multiple intensity levels and frequencies in subjects with normal hearing. *Am J Audiol* 2018;27(3):294–305
- 11 Cobb KM, Stuart A. Neonate auditory brainstem responses to CE-Chirp and CE-Chirp octave band stimuli I: versus click and tone burst stimuli. *Ear Hear* 2016;37(6):710–723
- 12 Ferm I, Lightfoot G. Further comparisons of ABR response amplitudes, test time, and estimation of hearing threshold using frequency-specific chirp and tone pip stimuli in newborns: findings at 0.5 and 2 kHz. *Int J Audiol* 2015;54(10):745–750
- 13 Rodrigues GRI, Ramos N, Lewis DR. Comparing auditory brainstem responses (ABRs) to toneburst and narrow band CE-chirp in young infants. *Int J Pediatr Otorhinolaryngol* 2013;77(9):1555–1560
- 14 Ferm I, Lightfoot G, Stevens J. Comparison of ABR response amplitude, test time, and estimation of hearing threshold using frequency specific chirp and tone pip stimuli in newborns. *Int J Audiol* 2013;52(6):419–423
- 15 Megha KN, Divyashree KN, Lakshmi A, et al. Narrow-band chirp and tone burst auditory brainstem response as an early indicator of synaptopathy in industrial workers exposed to occupational noise. *Intractable Rare Dis Res* 2019;8(3):179–186