Advantages of Narrow Band CE-Chirp ABR Compared to Tone Burst ABR in Adults with Normal Hearing

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Abstract

Objectives: In this study, we aimed to compare the ABR's (Auditory Brainstem Response) estimated behavioral thresholds, wave V latencies, and amplitudes, obtained using Tone Burst and Narrow Band (NB) CE-Chirp stimuli in adults with normal hearing. Design: A prospective study was designed. Setting: Otorhinolaryngology and Audiology Clinic of the tertiary university. Participants: Twenty-four adults with normal hearing (17 males, 7 females) participated in this study. Main outcome measures: ABR was recorded using Narrow Band (NB) CE-Chirp and Tone Burst (TB) for four frequencies (0.5, 1, 2, 4 kHz). Wave V obtained for 60, 40, and 20 dB nHL intensity levels for both two procedures. Behavioral hearing thresholds (BHT) were identified at 0.5, 1, 2, 4 kHz. Duration of TB and NB CE Chirp ABR tests for each ear was recorded. Wave V latencies, amplitudes, BHTs, duration of tests were compared. Results: The thresholds obtained from NB CE-Chirp stimulus (20, 19, 16, 15 dB nHL) at 0.5, 1, 2 and 4 kHz were significantly closer to the behavioral hearing thresholds (11, 10, 9, 9 dB HL) compared to Tone Burst ABR thresholds (25, 23, 20, 19 dB nHL) (at all frequencies $p < 0.001$, CI = 2.0- 5.9). The absolute latencies of peak V with TB stimuli were significantly longer than latencies obtained with NB CE Chirp stimuli at 0.5, 1, and 2 kHz at all sound intensity levels ($p<0.001$). The mean test time for NB CE-Chirp ABR was 23.6 ± 3.9 minutes and significantly shorter than the TB ABR test time (28.2 ± 4.5), ($p=0.011$). Conclusion: Frequency-specific behavioral thresholds are estimated better with NB CE-Chirp than TB ABR.

Key Points:

1- NB CE-Chirp ABR thresholds were found closer to PTA thresholds than the TB ABR thresholds.

2- NB CE-Chirp ABR significantly shortens the test time.

3- Chirp stimulus is more available for hearing screening.

4- NB CE-Chirp ABR can be used in the prediction of behavioral hearing thresholds in adults whose behavioral hearing thresholds are difficult to determine.

5- Chirp stimulus provides larger and more detectable wave V amplitudes according to Tone Burst.

1. Introduction

The auditory brainstem response (ABR) is an objective method to evaluate the neurologic functioning of the auditory pathway, auditory brainstem neurologic integrity, and an estimate of hearing thresholds in individuals (1). ABR waveforms include a series of positives and negatives waves occurring during the first 10 ms following an acoustical stimulation. They reflect the synchronous activity of the auditory system, and phrases with roman numerals (I–V) (2). (ABR) is used in children and adults for universal newborn hearing screening, evaluation of hearing functions, diagnosis of peripheral and central nervous system diseases, and

also intraoperative monitoring (3, 4). The ABR evaluation represents a standardized and comprehensive method for determining the potential risk of drug-induced hearing dysfunction (5). Also, ABR studies have reported abnormal (prolonged) latencies for waves III and/or V with autism spectrum disorders (6). Stimulus variants used in ABR according to frequency bands (350-10,000 Hz) are click stimulus (all frequency bands), Tone-Burst (TB) stimulus (narrow frequency band) and chirp stimulus (1, 7). Chirp stimulus was developed to compensate for the delay of the cochlear wave traveling in ABR by stimulated different neural units along with the cochlear partition. (8). Different models of chirp stimulus have been identified in the literature to obtain efficiently ABR (9, 10).

Tone-Burst (TB) stimulus type is widely used to obtain frequency-specific responses (11). However, the TB stimuli causes cochlear wave travelling delay in a specific frequency range (12). It is also difficult to identify the wave V at low stimulus levels (<60 dB nHL) with Tone-Burst stimuli (13). Although the design of CE-Chirp stimulation is an important development in the auditory electrophysiological field, CE-Chirp stimulus is insufficient in the estimation of frequency-specific thresholds (14). The Narrow Band (NB) CE-Chirp stimulus has been developed for compensating for some deficiencies of the Tone-Burst stimulus (9, 15). NB CE-Chirp stimulus has designed for including four central frequencies as 0.5, 1, 2, 4 kHz. The stimulated area of the NB CE-Chirp stimulus is slightly wider than the TB stimulus and allows synchronized firing of different neural units along the base to the apical end of the cochlea. (3). Ferm et al. (16) compared NB Chirp and TB ABR and NB CE-Chirp ABR wave V amplitudes were found to be larger than TB ABR wave V amplitudes. Rodrigues at al.(12) detected that NB CE-Chirp ABR wave V amplitudes were greater than TB ABR wave V amplitudes at all levels except 500 Hz 80 dB nHL.

Studies about the behavioral hearing thresholds (BHT) estimation by electrophysiological methods are up to date in the literature(17). For many years, TB ABR has been used to estimate behavioral hearing thresholds (18). The elimination of the delay in the cochlear traveling wave with the chirp stimulus and the synchronous stimulation of the afferent nerves are superior to the traditional click stimulus. For this reason, studies about the prediction of behavioral hearing thresholds with chirp stimulus are increasing in the recent literature (19). BHT is used clinically to detect hearing loss and to prescribe the amplification of suitable hearing aids (20). In determining hearing thresholds, PTA is used preferential, and Tone Burst ABR is commonly used in children with hearing loss and neurological disease (21, 22). Also, repeated measurements showed that hearing thresholds may be detected false and not consistent with previous thresholds in 50% of newborns with hearing loss, therefore the accurate estimation of thresholds becomes essential (22).

In addition, there may be adults who cannot fully adapt to subjective hearing tests (PTA). This can happen due to poor understanding of the test procedure and low motivation. Even though there is no pathology in the hearing system, people can act as if they have a hearing loss to get personal or financial profit. This situation is called “nonorganic hearing loss”, “pseudohypacusis” or “functional hearing loss” (23). It is difficult to accurately determine behavioral hearing thresholds in adults with nonorganic hearing loss or and intellectual deficit.

In this study, we aimed to determine which Tone Burst ABR and NB CE-Chirp ABR thresholds are closer to frequency-specific behavioral hearing thresholds in normal hearing adults. Thus, it can be determined which ABR stimulus is more effective in estimating hearing thresholds in adults whose behavioral hearing thresholds are difficult to determine

Accurate estimation of frequency-specific hearing thresholds can also allow proper hearing aid adjustment in adults with hearing loss and intellectual deficit.

2. Materials and methods

2.1Study Design: This study designed prospectively in the audiology department of a tertiary university hospital between June 2018 and October 2018. The study included 24 adults (17 males, 7 females) aged 20-48 years with normal hearing. Participants were tested in a sound-treated room, pure-tone audiometer Interacoustics model AC40 (calibrated as per ANSI S3.6, 1996) (Interacoustics AS, Assens, Denmark). Pure-tone audiometry for both air conduction (for the frequency range 250–8000 Hz) and bone conduction (for

the frequency range: 500–4000 Hz) were tested using headphones TDH 39 (Telephonics Co.Farmingdale, NY, USA) and bone vibrator RadioEar B-71 (RadioEar Co. Middelfart, Denmark). Only those participants whose hearing sensitivity was [?] 20 dB HL at each frequency (250-8000) without any otological, psychological or neurological dysfunction were selected for the study. ABR recordings were taken using the Eclipse Ep 25 ABR system.

The assessment was done with two stimuli namely, NB CE-Chirp and Tone Burst at four frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. The stimuli were calibrated to ISO 389-6 (2007) for the click and to manufacturer's data for the chirps. Positive (active) electrode was placed on the top of the forehead (Fz), ground electrode was placed at the bottom up the forehead (Fpz), reference electrodes were placed on the right (M2) and left (Ml) mastoids, The measured potentials were recorded with impedance below 5kΩ.

The four (0.5, 1, 2, 4 kHz) Tone Bursts and NB CE-Chirps® were presented with rarefaction polarity through insert ER-3A (Etymotic Research) earphones at a rate of 44.1/s. Measurements were carried out using High Pass Filter (HPF): 75 Hz and Low Pass Filter (LPF): 1500 Hz. Tone Bursts and Narrow Band CE-Chirps were presented monaurally.

ABRs records obtained for 0.5, 1, 2, 4 kHz and 60, 40, and 20 dB nHL intensity levels for both Narrow Band (NB) CE-Chirp and Tone Burst (TB) stimuli. Behavioral hearing thresholds (BHT) were identified at 0.5, 1, 2, 4 kHz. The ABR threshold was taken as the lowest of levels containing a clear response. Tests were started from 60 dB nHL level, stimuli were decreased until no response was obtained. Initially 10 dB nHL decreases were used to estimate BHT, and then 5 dB nHL changes were made to determine a clear wave V response. Each measurement was carried out using an average of 2000 sweep to clarify the waveforms.

The absolute peak amplitude and absolute peak latencies were recorded for wave V in all four frequencies (0.5, 1, 2, 4 kHz) for TB and NB CE-Chirp stimulus. ABR wave V amplitudes and absolute latencies were determined by visual inspection. Duration of TB and NB CE Chirp ABR tests for each ear was recorded. The study was prepared with the reporting guideline of the STROBE checklist.

2.2. Participants: Inclusion criteria were: adults with no history neurological or otological dysfunction and audiometric thresholds [?] 20 dB HL for the 250-8000 Hz frequencies. Patients with hearing loss, neurological, psychological were excluded from the study. Also, patients with previous ear surgery, chronic otitis media, Meniere's disease, subjective tinnitus, tympanosclerosis were excluded, Patients with chronic systemic disease (diabetes mellitus, autoimmune diseases), chronic systemic drug use were not included in the study.

2.3. Statistical Analysis: Results were analyzed with the SPSS 22.0 package program. Threshold values were compared with the Paired t-test and test times were compared with the Wilcoxon test and the results with p significance value less than 0.05 were considered as significant. Intraclass correlation coefficient (ICC) was used to determine consistency of thresholds identify by PTA, TB, and NB CE-Chirp stimulus. Sample calculation and power analysis were assessed with the G Power 3.1 package program. By using the result of similar research of Mourtzouchos and et al. (24), the effect size (d) 1.21 specified as α=0.05 and β=0.80 and the sample size was calculated as 20.

2.4. Ethics Committee Approval: Verbal and written consent was obtained after all participants were informed. This study was conducted in accordance with the Declaration of Helsinki. Ethics committee approval was obtained.

3. Results

In this study, Tone Burst and NB CE-Chirp ABR data of 24 adults (31 ears) were analyzed retrospectively. The tests could not be completed in both ears, since 17 individuals could not tolerate repeated ABR measurements for each ears. The mean age of the participants was detected at 30.4 ± 8.6 (min: 20 max: 48). Test data of 18 ears from 17 men and 13 ears from seven women were analyzed. The research included 18 (58.1%) right ears and 13 (41.9%) left ears. The absolute latencies of peak V with TB stimuli were significantly longer than latencies obtained with NB CE Chirp stimuli at 0.5, 1 and 2 kHz at all sound intensity levels ($p<0.001$)

(Figure 1, 2) . There was no difference between TB ABR and NB CE-Chirp ABR latencies at 4 kHz-20 dB nHL (p=0.374) **(Table 1)** . The amplitudes of peak V detected with NB-CE Chirp were significantly larger than TB amplitudes in the level of 4 kHz 60 dB nHL (p=0.038). However, there was no significant difference was detected at other frequencies for the amplitude in both TB and NB CE-Chirp ABR (p>0.05).

NB CE-Chirp ABR threshold values closer to PTA 0.5 1, 2 kHz thresholds than the TB ABR thresholds (p<0.001, CI=2.0-5.9 dB)**(Table 2) (Figure 3).** While the thresholds obtained with PTA, TB and NB CE-Chirp stimuli were showing the highest correlation at the 2 kHz, the least correlation between the measurements was found at 4 kHz (respectively ICC= 0.855 and 0.673), **(Table 2).** The correction factor, which was calculated from the mean difference in the paired t-test, between thresholds obtained from NB CE-Chirp and TB stimuli and BHT determined by PTA is given in Table 3. In the posthoc power analysis, the power for the difference between the threshold values at all frequency and all sound intensities was measured as 90% and above.

There was no significant difference between thresholds obtained from PTA, TB and NB CE-Chirp for right and left ears at all frequencies (p>0.05, paired t-test). While the most consistent (test-retest reliability) threshold value obtained with PTA at 4 kHz frequency with TB ABR in the right ear (r=0.709, p=0.001), it obtained at 2 kHz with NB CE-Chirp ABR in the left ear (r= 0.743, p= 0.004). The estimated thresholds were similarly correlated with PTA in the right and left ears. The mean test time with NB CE-Chirp ABR was calculated as 23.6 ± 3.9 minutes and the mean test time with Tone Burst ABR was measured as 28.2 ± 4.5 minutes. NB CE-Chirp ABR test time was significantly shorter than the TB ABR test time (p=0.011).

4. Discussion

Ferm et al. (16) compared NB Chirp and Tone pip ABR findings at 1 and 4 kHz and 40 dB nHL of 42 ears of 30 infants in the newborn screening program. As a result of this study, NB CE-Chirp ABR wave V amplitudes were found to be larger than Tone pip ABR wave V amplitudes (p=0.001). In 40 children with normal hearing, the findings of the 0.5, 1, 2, 4 kHz NB CE-Chirp ABR and Tone-Burst ABR were compared at 80, 60, 40, 20 dB nHL by Rodrigues at al.(12). At all levels except 500 Hz 80 dB nHL, NB CE-Chirp ABR wave V amplitudes were found to be greater than Tone-Burst ABR wave V amplitudes (p<0.05).

In our study, only at 4 kHz 60 dB nHL level, NB CE-Chirp ABR wave amplitudes were found to be greater than TB ABR wave amplitudes (p=0.038). Similar to our research results, Megha et al. (25) found no significant difference in any of the frequencies for amplitude parameter in TB and NB CE Chirp ABR. At high levels of chirp stimulus, desynchronization develops as a result of overstimulation on the cochlear basilar membrane. As a result, it is stated that the wave V amplitudes decrease (25-27). This effect can be observed, especially when a high stimulus level is sent to subjects with normal hearing (25, 27).

Studies comparing NB CE-Chirp ABR and Tone Burst ABR in the literature were frequently conducted with infants. For example, Rodrigues et al. (12) found that NB CE Chirp ABR latencies were shorter than Tone Burst ABR latencies in infants at 0.5, 1, 2 kHz. In this study; the mean wave V latency evoked by 500 Hz (60 dB nHL) NB CE-Chirp was found to be 3.57 (SD: 0.70). In this study, longer wave latencies were found compared to our research. Because the value of the peak V latency varies among different age person (28). Our study was carried out with adults.

Megha et al. (25) conducted a study that researched the effects of noise using NB CE Chirp ABR and TB ABR. Similar to our research, in this study; the mean wave V latency evoked by 500 Hz NB CE-Chirp was found to be 2.45 (SD: 0.68) in the control group with normal hearing. Especially at low frequencies, NB CE-Chirp ABR wave V latencies were observed to be very short. For Tone Burst stimulus, the ABR mean latencies increased with decrease in frequency. But NB CE-Chirp stimulus, the ABR means latencies decreased with decrease in frequency. This is explained by eliminating the delay in the cochlear travelling wave by using different transmission times for each of the chirp stimulus frequencies. The low frequencies in the NB CE-Chirp are being presented early than high frequency octave bands. Thus NB-CE Chirp provides maximum stimulation into the cochlea (12, 25).

Ferm et al. (16) reported that the NB CE-Chirp ABR thresholds were found to be lower than the tone pip thresholds. For this reason, it was emphasized that NB CE-Chirp stimulus can provide closer responses to behavioral thresholds.

In our study, ABR thresholds with Narrow Band CE-Chirp stimulus at 0.5, 1 and 2 kHz were found significantly closer to the behavioral hearing thresholds compared to Tone Burst ABR thresholds ($p<0.001$, CI=2.0-5.9). Talaat et al. (29) investigated which of the NB CE-Chirp ABR and Tone Burst ABR thresholds were closer to the frequency specific behavioral hearing thresholds. As a result, it was stated that NB CE Chirp-ABR provides higher sensitivity and accuracy than TB ABR in estimating behavioral hearing thresholds in young children. Van et al. (30) compared the proximity of NB CE-Chirp ABR and Tone Burst ABR thresholds to behavioral hearing thresholds in 23 adults with normal hearing. In this study, it was stated that using NB CE-Chirp is more reliable than TB ABR in estimating behavioral hearing thresholds. Similarly, the ASSR thresholds determined by the NB CE-Chirp stimulus are highly correlated with the behavioral thresholds (0.5, 1, 2, 4 kHz) defined with PTA according to the TB ABR thresholds (31, 32).

The hearing thresholds specified as dB nHL in ABR is not equal to behavioral thresholds determined as dB HL. As a result, it is suggested to use the correction factor when calculating BHT thresholds (dB HL) from the thresholds (nHL) determined by ABR (25, 28). The correction factor, which is used to estimate behavioral hearing thresholds with using of NB CE-Chirp ABR, can be reduced by up to 5 dB (21, 16).

The shortening of the test time with NB CE-Chirp stimulus is another advantage. ABR amplitudes are not detectable in 30 % of the click stimulus and need more test time. Click stimulus produces larger and easily detectable amplitudes. Likewise, the mean test time of NB CE-Chirp ABR was detected shorter than the mean test time of TB ABR in our research ($p=0.011$). Similarly to this study, Zirn et al. (33) compared the duration of the test conducted with both ABR methods in their study including 253 children, and as a result, NB CE-Chirp ABR was found to shorten the recording time. Ferm et al. (16) reported that the use of NB CE-Chirp stimulation produced larger response amplitudes, and therefore increase the signal to noise ratio according to TB clicks, so shortens the test time.

Conclusion

In our study, NB CE-Chirp ABR thresholds were found closer to PTA thresholds than the TB ABR thresholds. NB CE-Chirp ABR significantly shortens the test time. It has been observed that NB CE-Chirp ABR can be used in the prediction of behavioral hearing thresholds in adults whose behavioral hearing thresholds are difficult to determine. In mental retarded patients with hearing loss, proper hearing aid adjustment can be made as a result of accurate estimation of frequency specific hearing thresholds. But the research needs to be repeated in larger samples using appropriate randomization and blinded study protocol.

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Data Availability Statement: The data can be shared upon request.

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Tables

Table 1 Comparison of the absolute latency of peak V between Tone Burst and Narrow Band CE-Chirp with t-test statistics.

		Mean latency (ms) of peak V for TB and NB-CE-Chirp ABR (msn ± sd)	**Mean latency (ms) of**
		500 Hz	**500 Hz**
		60 dB	**40 dB**
S	**TB**	8.8±0.9	10.3±1.1
	NB	2.7±0.4	4.6±0.6
p	**p**	0.0001	0.0001
CI	**CI**	5.7-6.3	5-6.1

TB: Toneburst. NB: Narrow Band CE-Chirp, S: Stimulus, CI: %95 Confidence interval, m±sd: mean ± standard deviation

Table 2 Tone Burst ABR and NB CE-Chirp ABR thresholds obtained at different frequencies with Pearson correlation and paired t-test statistics according to PTA thresholds.

T	T	Threshold values dB(m ± sd) and Pearson r and p values	Threshold values dB(m ± sd) and
		500 Hz	**r**
S	**PTA**	11.2±4.4	
	TB	24.8±5.6	0.532
	NB	20.6±3.8	0.487
ICC	**ICC**	0.761	0.761

PTA: Pure Tone Audiometry, TB: Toneburst, NB: Narrow Band CE-Chirp, S: Stimulus, ICC: Intraclass Correlation, m±sd: mean ± standard deviation, T: Total of Ear

Table 3 Correction factors for Tone Burst and NB CE-Chirp thresholds according to PTA thresholds and t-test statistics.

Total of ears	Total of ears	Correction factors for thresholds according to PTA* (mdB)	Correction facto
		500 Hz	1000 HZ
s	**TB**	-14	-12
	NB	-9	-8
p	**p**	0.0001	0.0001

PTA: Pure Tone Audiometry, TB: Tone Burst, NB: Narrow Band CE-Chirp, S: Stimuli, mdB: mean dB, T: Total of Ear,*: mean of %95 CI of Difference.

Figures

Figure 1 Tone Burst and NB-CE-Chirp responses at 500 Hz

Figure 2 Tone Burst and NB-CE-Chirp responses at 1000 Hz

Figure 3 Thresholds for NB Chirp ABR and TB-ABR and PTA in adults with normal hearing