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Original articles

Estimated thresholds (est dBHL) for auditory evoked potentials with narrowband CE-Chirp® stimuli

Miguel Fuentes[1]
Robinson Barrientos[2]
Sofía Bravo[3]

[1] Universidad de Magallanes, Punta Arenas, Chile.
[2] Universidad de Playa Ancha, Valparaíso, Chile.
[3] Universidad Nacional Andrés Bello, Santiago, Chile.

ABSTRACT

Purpose: to correlate pure-tone audiometry thresholds with electrophysiological thresholds, using NB CE-Chirp® stimuli in listeners aged 18 to 30 years from Santiago, Chile, and determine the estimated threshold at 500, 1000, 2000, and 4000 Hz. This can contribute to the battery of objective and subjective tests applicable to children, aiding the timely detection and implementation before 3 months old, as recommended by the Joint Committee on Infant Hearing.

Methods: a quantitative, nonexperimental study with a sample of 30 hearing subjects, aged 18 to 30 years. The Pearson´s correlation test was applied, with a significance p-value of 0.01.

Results: higher frequencies (2000 and 4000 Hz) have lower correction factors than medium and lower frequencies (1000 and 500 Hz), which tend to be higher as the frequency is lower.

Conclusions: the study obtained the following estimated thresholds: 15 dB at 500 Hz, 10 dB at 1000 and 2000 Hz, and 5 dB at 4000 Hz.

Descriptors: Auditory Threshold; Evoked Potentials, Auditory, Brain Stem; Electrophysiology

A study conducted at the Universidad Nacional Andrés Bello, Santiago de Chile, Chile.

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Corresponding author:
Miguel Fuentes
Calle proyectada 4, 01766
Código postal: 6200000 - Punta Arenas, Chile
E-mail: miguel.fuentes@umag.cl

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INTRODUCTION

Evoked potentials are sensitive, objective, reliable, reproducible neurophysiological procedures harmless to the patient, intended to assess the integrity of the sensory and motor pathways. Visual (VEP) and somatosensory evoked potentials (SEP) are among the most studied ones[1]. Auditory evoked potentials (AEP), approached in this study, are also among the most widely used techniques, addressing the cochlear nerve, brainstem, and auditory cortex responses to auditory stimuli. This technique represents the electrophysiological response of the auditory pathway up to the brainstem – which is why it is also called auditory brainstem response (ABR) or short-latency auditory evoked potentials[2].

Two of the main ABR applications are found in clinical practice. The first aims to achieve the topological diagnosis of hearing loss, and the second aims to obtain the electrophysiological threshold that responds to the minimum intensity at which wave V is visible. These thresholds are not directly equivalent to the audiometric thresholds, so a correction factor must be applied to determine an estimated threshold (est dBHL). This function is useful, especially in children, as it approximately correlates audiometric with electrophysiological thresholds – although it has its limitations for not considering a wider range of low frequencies[3].

The ABR is used to assess hearing sensitivity in patients who cannot provide reliable hearing thresholds using voluntary behavioral methods, such as pure-tone audiometry. Although the ABR is a synchronized neural function test and not a direct hearing test, its results can be used for inferences regarding hearing sensitivity since they show the behavior of the afferent auditory pathway in response to different intensities (generally between 10 and 100 dBnHL). Thus, the electrophysiological threshold can be established (corresponding to the minimum intensity in dBnHL at which wave V can be visualized) and correlated to the patient's behavioral thresholds[4].

Even though electrophysiological thresholds do not coincide completely with pure-tone thresholds, they are highly correlated thanks to the correction factor commonly applied by clinicians in electrophysiology. The correction factor is the subtraction of the pure-tone or behavioral threshold from the electrophysiological threshold obtained at each frequency. For broadband tones (e.g., click), the correction factor is set around 10 to 20 dB lower than the electrophysiological threshold, thus obtaining an "estimated" behavioral threshold, sometimes called est dBHL[4,5].

Accurate diagnosis or electrophysiological audiogram is possible by using various stimuli that focus their acoustic energy on a narrow band of frequencies with more language information. Tone burst (TB) is a transient signal at 500, 1000, 2000, or 4000 Hz, characterized by a rapid onset and short duration, resulting in a wide energy spectrum in the frequency domain. This type of stimulus occurs at a higher latency than a click tone, with the onset time being longer at low than at high frequencies, due to the path that the acoustic energy must travel to stimulate the basilar membrane in its most apical portion[5].

The broadband CE-Chirp® stimuli are designed with a delay in the components that reach the base of the cochlea so that the entire basilar membrane is activated at the same time. The narrowband (NB) CE-Chirp® stimuli are based on the same model as the broadband CE-Chirp® tones, producing a delay of their higher frequency components to achieve better neural synchrony. The stimulation sectors in this case are broken into four frequencies: 500, 1000, 2000, and 4000 Hz[6].

These stimuli are based on models that compensate for the sound wave's travel through the cochlea, allowing for better response visualization and decreased test application times[7]. NB CE-Chirp® stimuli are an alternative to the already known TB, designed with components restricted to only one frequency band, focusing on 500, 1000, 2000, and 4000 Hz[8].

In the same way as broadband CE-Chirp tones, this type of stimulus has a greater response amplitude than TB. This should provide responses whose time is close to the known click stimuli but centered on a specific frequency band[9].

The broad response to NB CE-Chirp® stimuli may result from various mechanisms. First, they were designed with a time compensation or delay incorporated into the selected octave filter (500, 1000, 2000, and 4000 Hz) and with a wider bandwidth than the TB, encompassing the frequency ranges of 500 (375 – 750), 1000 (750 – 1500), 2000 (1500 – 3000), and 4000 (3000 – 6000 Hz). This spectral width would activate more nerve fibers[10,11].

Hence, they increase the synchronous activity of the nerve fibers on the basilar membrane, thus achieving broader responses than with other types of stimuli by specific frequency. This facilitates the visual identification of peaks in the response, reducing the gap between stimulus and frequency specificity[12].

Studies show that NB CE-Chirp® tones generate a lower latency than TB at 500, 1000, and 2000 Hz, as well as greater amplitudes at low intensities, which would respond to the difficulties found with TB regarding the visualization of wave V at low and medium frequencies (500 and 1000 Hz) – especially in the case of hearing loss, as neural synchrony is altered in terms of amplitude and latency onset. The temporal compensation of NB CE-Chirp® stimuli produces greater neural synchrony and, consequently, a response that clinicians can visualize more easily. The amplitude recorded at 80 dBnHL is not significantly different between the stimuli. However, at lower intensities (30 to 20 dBnHL), NB CE-Chirp® tones show greater amplitudes than TB, resulting in great utility when establishing the electrophysiological threshold, especially in low tones[5,8,13].

In this regard, Bargen (2015)[14] indicates that due to these wave amplitude characteristics, the correction factor for CE-Chirp® is reduced or can be eliminated. However, it is important to measure it with each device and population[14]. In the case of NB stimuli, Hall (2013)[10] proposes a correction factor of 15 dB for 500 Hz and 10 dB for the other frequencies with TB, which could be taken as a reference for NB stimuli. Moreover, Bagatto, in Hall (2013)[10], proposes 20, 15, 10, and 5 dB, respectively, while the British Columbia Early Hearing Program proposes 15, 10, 5, and 0 dB[6,10]. Recent studies have compared behavioral thresholds with nHL thresholds using NB CE-Chirp® and TB and determined that the former were significantly closer to the audiometric thresholds than the Chirp tones, with differences of 9, 9, 7, and 6 dB when compared with the audiometric threshold[10,15].

This study aimed to correlate pure-tone audiometry thresholds with electrophysiological thresholds, using NB CE-Chirp® stimuli in listeners aged 18 to 30 years from Santiago, Chile, and determine the estimated threshold at 500, 1000, 2000, and 4000 Hz. This can contribute to the battery of objective and subjective tests applicable to children, aiding the timely detection and implementation before 3 months old, as recommended by the Joint Committee on Infant Hearing[16].

METHODS

This study was presented to the Bioethics Committee of the School of Rehabilitation Sciences at the Andrés Bello National University of Chile. The project was submitted with the entry number 00187. All subjects participating in this study signed an informed consent form.

This is a quantitative, nonexperimental, cross-sectional study, with a descriptive-correlational approach. The Pearson´s correlation test was applied, with a significant p-value of 0.01.

The investigation used a two-channel audiometer (Interacoustics AC 40) and an ABR device (Interacoustics Eclipse EP 25) with ABR 3A insert earphones.

The sample had 30 listeners, with normal audiometry thresholds according to the World Health Organization (WHO-2015) – up to 25 dBHL –, who underwent a previous otoscopy and impedance evaluation, revealing no changes. The sample size was calculated, requiring 40 subjects with a minimum of 30 analysis units.

The sampling procedure had the following evaluations: first, pure-tone audiometry in a sound booth using the descending method; second, bilateral ABR with NB CE-Chirp® tone, applying the descending method, with impedance < 3 kΩ, using cup electrodes with conductive paste, LP 1500 Hz-HP 33 Hz filters, alternating polarity, and a rate of 37.1, 39.1, 45.1, and 49.1 presentations per second (500 to 4000 Hz). Two traces were made for each evaluated intensity and frequency to corroborate reproducibility.

RESULTS

The results showed a close correlation with other types of stimuli when applying the suggested correction factors. Correction factors are lower at 2000 and 4000 Hz than at 1000 and 500 Hz – hence, they tend to be higher as the frequency is lower.

The statistical analysis showed median pure-tone threshold differences of 10 dB at 1000 to 4000 Hz and 7.5 dB at 500 Hz. On the other hand, it showed median nHL thresholds of 20 dB at 500 to 2000 Hz and 15 dB at 4000 Hz (Chart 1).

Chart 1. Statistical analysis of pure-tone thresholds and electrophysiological threshold with Narrow Band CE-Chirp® stimuli

Frequencies	500 Hz/dBHL	1000 Hz/dBHL	2000 Hz/dBHL	4000 Hz/dBHL
n	30	30	30	30
Median	7.5	10	10	10
Mode	10	5	5	15
Minimum	0	0	0	0
Maximum	20	20	20	20
Mean	7.5	8.5	8.67	9.17
Frequencies	**500 Hz/dBnHL**	**1000 Hz/dBnHL**	**2000 Hz/dBnHL**	**4000 Hz/dBnHL**
n	30	30	30	30
Median	20	20	20	15
Mode	20	20	20	20
Minimum	20	15	15	10
Maximum	35	25	20	20
Mean	22.5	18.33	17.67	15.83

Captions: dBHL = pure-tone audiometry threshold; dBnHL = electrophysiological threshold; NB = narrowband; n = number.

The difference between pure-tone and electrophysiological thresholds showed equal medians of 10 dB at 1000 and 2000 Hz. On the other hand, the medians at 500 Hz were 15 dB, whereas the difference between the two variables at 4000 Hz was only 5 dB (Chart 2).

Chart 2. Statistical analysis of the difference between electrophysiological threshold findings with Narrow Band CE-Chirp® stimuli and pure-tone audiometry threshold

DIFFERENCE	Difference 500 Hz	Difference 1000 Hz	Difference 2000 Hz	Difference 4000 Hz
n	30	30	30	30
Median	15	10	10	5
Mode	15	10	10	5
Minimum	5	5	0	0
Maximum	20	20	15	15
Mean	15	9.83	9	6.66

Captions: n = number.

The correlation analysis with the Pearson´s correlation test indicated a high correlation for 500 and 4000 Hz and a medium correlation for 1000 and 2000 Hz. These results indicate that the differences obtained are constant (Chart 3).

Chart 3. Correlation obtained with the Pearson´s correlation test for electrophysiological threshold with Narrow Band CE-Chirp® stimuli and pure-tone threshold

Pearson´s correlation for thresholds per frequency (Hz)		Significance (bilateral)
500 Hz/ dBHL 500 Hz/ dBnHL	0.686	0.000
1000 Hz/ dBHL 1000 Hz/ dBnHL	0.575	0.001
2000 Hz/ dBHL 2000 Hz/ dBnHL	0.583	0.001
4000 Hz/ dBHL 4000 Hz/ dBnHL	0.806	0.000

Captions: dBHL = pure-tone audiometry threshold; dBnHL = electrophysiological threshold.

DISCUSSION

The results obtained in this investigation refer to the correlations between pure-tone thresholds and electrophysiological thresholds with NB CE-Chirp® stimuli in 30 hearing subjects, aged 18 to 30 years, to determine the estimated thresholds (est dB).

The mean difference between pure-tone and electrophysiological thresholds at 500 Hz was 15 dB, which coincides with the median value. Clinical evidence suggests that the 500 Hz tone is historically the most complex to identify in clinical practice, mainly for two reasons. The first one has to do with its onset latency because the tone sent through the earphone must travel longer through the cochlea, so wave V is delayed more than at higher frequencies, requiring extensive analysis windows (even 20 ms in cases of hearing loss), which makes its visualization difficult[12]. The second reason has to do with physiological factors during the wave's travel through the cochlea, as low-frequency components must travel longer to reach the desired stimulation point; thus, that part of the energy is lost along the way, directly affecting the wave V amplitude, making it difficult to view and reproduce it[13].

This study reveals that thanks to the NB CE-Chirp® design and the temporal compensation of the frequency components, it is possible to achieve greater neural synchrony, improving the signal-to-noise ratio and, consequently, observing a greater amplitude – which facilitates the identification of the components, especially at low intensities (< 30 dBnHL). On the other hand, the studies by Rodríguez (2013)[7] show a direct relationship between the latency and frequency of the stimulus presentation, so that the 500 Hz tone has an earlier onset than stimuli such as TB, removing the temporal limitation.

The 500 Hz tone differed the most from the pure-tone threshold among the four frequencies studied. This is due in part to what was reported by Ribeiro (2013)[17], who explains that part of the spectral energy is lost as the wave travels through the cochlea until it reaches the peak. However, this difference does not seem significant from a practical standpoint since the electrophysiological threshold does not necessarily have to have the same value as the behavioral threshold, because the neuronal activation must be picked up by the electrodes located on the skin (far field) – thus, electrophysiological thresholds will always be equal to or greater than those recorded through pure tones[5,8].

The mean difference between pure-tone and electrophysiological thresholds at 1000 Hz was 9.83 dB, which is close to the median differences. These values are lower than with the 500 Hz stimulus, with narrower differences than with other types of stimuli (such as TB and modulated tones) used in electrophysiology to estimate NB thresholds. Compared to the former, 1000 Hz NB CE-Chirp® tones have better reproducibility at low intensities, which significantly impacts the amplitude and, consequently, a better visualization of wave V. Compared to the modulated tones of the steady-state evoked potentials, they have a narrower difference since the latter has means ranging from 11 to 14 dB regarding behavioral thresholds[18]. The 2000 Hz frequency has a mean difference of 9 dB, which is close to the median value (10 dB). At 4000 Hz, it has mean differences of 6.6 dB, with a median value of 5 dB.

According to the analysis, high frequencies (2000 and 4000 Hz) have a narrower difference from the pure-tone threshold. In most cases, even the electrophysiological threshold coincides with the behavioral threshold, because when the base of the cochlea is stimulated, significant spectral energy is not lost as it travels through the basilar membrane.

Hall (2013)[10] proposes a correction factor in TB application by subtracting 15 dB from the electrophysiological threshold at 500 Hz and 10 dB at the other frequencies (1000, 2000, and 4000 Hz). Based on this model, and as indicated by Megha (2019)[19], it may be possible to make the corrections recommended by the various clinicians. Furthermore, the corrections may be based on the means found in the present investigation (for the equipment used) to establish thresholds for electrophysiological audiograms – concerning this assessment, 15 dB at 500 Hz; 10 dB at 1000 Hz; 10 dB at 2000 Hz; and 5 dB at 4000 Hz. The values were estimated as multiples of 5 towards the nearest integer value for clinical applications, according to threshold search techniques. The results obtained in this research at 4000 Hz have an estimated threshold lower than that presented by other researchers – such as Ferm (2013)[12], who suggests a correction value of 10 dB. This difference may be due to the sample used, with 40 newborns in a hearing screening program, whereas the present study had hearing adults. Thus, the difference may be due to auditory pathway maturation.

Concerning the above, it confirms what was indicated by Seval (2020)[15], in that the thresholds obtained with NB CE-Chirp® stimuli are closer to behavioral audiometry thresholds than other electrophysiological thresholds, such as TB, providing greater sensitivity and precision in the estimation of behavioral auditory thresholds. This is due to the technology applied in NB CE-Chirp® tones regarding the delay of high-frequency components to achieve greater neural synchrony.

CONCLUSION

A stable relationship was found between the mean differences in pure-tone (dBHL) and electrophysiological (dBnHL) thresholds with NB CE-Chirp® stimuli. This provides a reliable correction value, enabling a more precise correlation to be used in clinical applications, and more specifically, an "estimated threshold", according to the frequency to be studied – which in this study was 15 est dBHL at 500 Hz, 10 est dBHL at 1000 and 2000 Hz, and 5 est dBHL at 4000 Hz.

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Authors' contributions:

MF: Conceptualization; Data curation; Data analysis; Methodology; Funding acquisition; Visualization; Writing - Original draft; Writing - Review & editing.

RB: Conceptualization; Data curation; Data analysis; Methodology; Funding acquisition; Visualization; Writing - Review & editing.

SB: Conceptualization; Data analysis; Funding acquisition; Visualization; Writing - Review & editing.

Data sharing statement:

The authors declare that individual participant data and other documents are not available.