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ORIGINAL ARTICLE

Relationship between Behavioral and Electrophysiologic Hearing Thresholds Using Narrow-Band Chirp-Evoked Auditory Brainstem Response

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ABSTRACT

Background: The Narrow-Band (NB) chirp stimuli induce a slightly wider stimulation of the basilar membrane around the 0.5, 1, 2, and 4 kHz frequencies, providing a closer auditory brainstem response (ABR) threshold to the behavioral one as compared to click-evoked ABR. Data regarding absolute and predicted hearing thresholds using NB chirp-ABR are lacking. This work aimed to evaluate the absolute and predicted hearing thresholds measured by NB chirp stimuli and to find the relationship between the electrophysiologic and behavioral hearing thresholds in adults with different degrees of sensorineural hearing loss (SNHL).
Methods: An observational, case-control study was conducted on 50 adults with normal hearing (control group) and 50 adults with mild to profound SNHL (study group). Both groups were age and gender matched. All participants were evaluated for their history, basic audiological evaluation and NB chirp-ABR assessment.
Results: The main NB chirp-ABR measures showed significantly longer latency, smaller amplitude, and lower mean electrophysiologic-behavioral threshold differences at higher degrees of SNHL. There was a moderate-to-strong positive correlation at normal and earlier degrees of hearing loss and a weak positive correlation at higher degrees between the electrophysiologic and behavioral thresholds. Moreover, regression equations predicted pure-tone thresholds from that of NB chirp-ABR.
Conclusions: The current results indicate that the NB chirp-ABR can be used effectively as a diagnostic tool to evaluate hearing thresholds in adults with different degrees of SNHL. Therefore, the NB chirp-ABR can be suggested to be applied to frequency-specific threshold estimation in difficult-to-test individuals.
Keywords: Absolute electrophysiologic threshold; Predicted behavioral threshold; Auditory brainstem response; Narrow band chirp-ABR; Adults

INTRODUCTION

Auditory brainstem responses (ABRs) are auditory evoked potentials emerging between 2-12 milliseconds after delivery of auditory stimuli. The click ABR method is the most frequently preferred method for ABR recording. The sudden start and broadband composition of the click synchronously activates a wide cochlear region [1]. However, it has been shown that the response to click is not completely synchronized. When a click reaches the basilar membrane, the resulting sound wave spends time moving through the stimulated area starting from the base to the apex of the basilar membrane. Therefore, the lower frequency region responds a few milliseconds later than the higher one [2]. More time is needed for the low-frequency region to reach maximum stimulation, a condition known as "the traveling wave delay" [1,3,4].
Another class of stimuli has been developed, the Claus Elberling-chirp (CE-chirp) stimulus, which creates more synchronous neural activity and consequently a more reliable ABR. The chirp stimulus was designed to produce simultaneous displacement by canceling travel-time differences along the cochlear partitions. Consequently, both the low- and high-frequency cochlear parts are stimulated and reach maximum depolarization simultaneously, causing a concurrent neural response with a larger wave V amplitude reported for ABR evoked by the chirp stimulus than that evoked by the click stimulus [5,6].
Later, Narrow-Band (NB) CE-chirps, centered on 0.5, 1, 2, and 4 kHz, became available. The NB-

chirp stimuli are ideal for electrophysiological frequency-specific threshold estimation [7]. They have been reported to provide a repeatable and reliable wave V response that is larger in amplitude than the wave V elicited by traditional click and tone-burst stimuli. The robust responses often arise with fewer averages reducing the evaluation time [7].

The frequency specificity of the NB stimuli allows for collecting more detailed ABR thresholds information. The NB chirps enable the assessment of hearing loss in a frequency-specific manner that might have been missed using a click or broadband chirp particularly low-frequency hearing loss with normal hearing in the higher frequencies [8].

In addition, some studies compared the proximity of the NB chirp-ABR and tone-burst ABR thresholds to the behavioral hearing thresholds in adults with normal hearing and different degrees of hearing loss. In these studies, NB chirp-ABR was more reliable than tone burst ABR in estimating behavioral hearing thresholds. Similarly, the auditory steady-state response (ASSR) threshold determined by the NB chirp stimulus was highly correlated with the behavioral thresholds [9] [10].

Few data are available regarding the absolute electrophysiologic-behavioral hearing threshold difference. No data about the predicted behavioral hearing threshold from the NB chirp-ABR are presented in literature. Therefore, this study was designed to estimate the absolute hearing threshold measured by NB chirp stimuli, to determine the mean difference between the electrophysiologic and behavioral hearing thresholds, to find the relationship between the electrophysiologic and behavioral hearing thresholds and to calculate a predicted pure tone hearing threshold from the electrophysiologic one by regression analysis in adults with normal hearing and different degrees of sensorineural hearing loss (SNHL).

METHODS

Participants

This observational, case-control study involved two groups; study and control groups recruited from the Audio-Vestibular Medicine Unit. The study group involved 50 participants (100 ears) of both genders ranging in age from 18 to 50 years. They had bilateral sensorineural hearing loss (SNHL) ranging from mild to profound across the hearing frequency range 0.25-8 kHz. The control group consisted of 50 adults (100 ears) with normal hearing sensitivity and they matched the study group regarding age and gender. The degree of the hearing was based on an air conduction audiogram according to Clark [11]: normal (less than or equal to 25 dB HL), mild (26-40 dB HL), moderate (41-55 dB HL), moderately-severe (56-70 dB HL), severe (71-90 dB HL), and profound (greater than 90 dB HL). Subjects were excluded from the study if they had an external ear pathology, a middle ear pathology or a retro-cochlear lesion.

Procedure

The study was performed from May 2020 to September 2021 at the Audio-Vestibular Medicine Unit, ENT Department, Zagazig University Hospitals, Zagazig, Egypt. Research procedure was explained to all participants before giving written consents to participate in the study. An approval ID: 6104-30-5-2020 has been obtained from the Institutional Review Board of Zagazig University.

The examinations were performed in one session that lasted about two hours. The study started with a complete history of hearing loss (side, onset, course and duration), a medical history of otological or neurological diseases and family history. An otoscopic examination was done to exclude external or middle ear disease. Basic audiological evaluation and NB chirp-ABR audiometry were performed.

Basic audiological evaluation:

The conventional pure-tone audiometry and speech audiometry were made in a sound-treated booth, using the two-channel diagnostic audiometer; Madsen (Model Oribter 902, version 2, Taastrup, Denmark). The stimuli were conducted through the TDH-39 supra-aural headphones. Conventional pure-tone audiometry included air conduction for octave frequencies 250 Hz through 8000 Hz and bone conduction for octave frequencies 500 Hz through 4000 Hz. In addition, speech audiometry involves a speech reception threshold (SRT) test using the Arabic bi-syllabic words for adults [12] and Word Recognition Scores (WRS) test using Arabic Phonetically Balanced Words for adults [12]. Moreover, immittancemetery was performed using the immittance-meter Madsen (model Zodiac 901 v. 3.2, Taastrup, Denmark) and involved the assessment of both tympanometry and acoustic reflex thresholds which were elicited contralaterally using pure tones of 500, 1000, 2000 and 4000 Hz.

Narrow-band chirp-evoked auditory brainstem response audiometry:

The ABR recordings were conducted in a sound-treated room via insert earphones (ER-3, Etymotic Research) using the auditory evoked system Oto-Access (v 1.3; Eclipse 25; Assens, Denmark) with 500 Hz NB chirp, 1000 Hz NB chirp, 2000 Hz NB chirp and 4000 Hz NB chirp. The stimuli were presented at a rate of 19.3 stimuli per second with alternating polarity. EEG activity was amplified by 60-80 dB with an artifact rejection level of 40 µV. The presentation level started at 90 dB normal hearing level (nHL) and was reduced in 20 dB steps until no response (wave V) was obtained then increased in 10 dB steps until wave V reappeared to estimate the electrophysiologic threshold.

The skin was prepared by scrubbing it with sandpaper to minimize the electrode impedance during contact between the electrodes and the skin. The electrodes utilized in the study were disposable electrodes that have a conductive gel. Four electrodes were used to pick up the response. They were placed according to the rules of the10-20 International System for EEG electrode placement. Two inverting electrodes were placed on the right and left mastoids. The non-inverting electrode was in the upper mid-frontal region (Fz position), and the ground electrode was in the lower mid-frontal region (Fpz position). Recordings were made with impedance less than 3 kΩ. The interelectrode impedance was maintained in equilibrium. The individuals were instructed to remain relaxed during recording with their eyes closed. During recording, a filter of 100 Hz to 3 kHz and 2000 Hz sweeps were utilized. The ABR traces were presented in a time window of 20 milliseconds. Two traces were obtained at each presentation level to ensure repeatability. Measures obtained from the NB chirp-ABR recording involved the detection of wave V and estimating its latency (in milliseconds) and amplitude (in µV) at the higher stimulation level, then the wave V was traced to a threshold level [13].

Statistical Analysis

Data were tabulated and analyzed using version 20.0 of the SPSS software (Armonk, New York: IBM Corporation). Frequency and percentage descriptions were provided for qualitative data. Chi-square test was used to compare percentages distribution. The Shapiro-Wilk test was employed to evaluate the distribution's normality. Range (minimum and maximum), mean, standard deviation (SD), and 95% confidence limits were used to characterize quantitative data. Student's t-tests and one-way ANOVA were used to compare between groups. Post-Hoc test was applied only after statistically significant results were found to determine where the actual differences existed among groups and subgroups. Wave V could not be detected in participants with profound hearing loss; thus, the NB chirp-ABR of this subgroup was not involved in the comparison between the groups. Pearson's correlation coefficient was used to correlate between the NB chirp-ABR threshold versus the pure-tone averages (0.25-4 kHz, 0.5-4 kHz, 1-4 kHz, 2-4 kHz, 0.25-8 kHz, 0.5-8 kHz, 1-8 kHz and 2-8 kHz) and pure-tone (0.25 kHz, 0.5 kHz, 1 kHz, 2 kHz, 4 kHz and 8 kHz) thresholds in the control group. Regression analysis was done between the best correlated dependent variable (pure-tone average or pure-tone) and the independent variable (NB chirp-ABR threshold). From the regression analysis, the regression equation was estimated; $y = a + b*x$, where: y was the dependent variable, a was constant value; line intercept; value of y when x is zero. b was slope of the regression line for the x variable; How much the y changes by each unit change of x. x was the independent variable. This equation was used to predict the behavioral hearing threshold (dependent variable) from the electrophysiologic threshold (independent variable). The obtained results were deemed significant at a *p* value less than 0.05.

RESULTS

The study involved two groups that were matching in age (control: 32.22 ± 8.39 years, study: 34.54 ± 8.69 years, t=1.63, p=0.178) and gender (control: males=44%, females=56%; study: males=54%, females=46%; X^2=1.00; p=0.317). The control group exhibited bilateral normal hearing sensitivity (≤ 25 dB HL). The study group participants had SNHL that ranged from mild to profound degrees. Figure 1 illustrates the mean hearing threshold of both groups across the frequency range of 0.25 to 8 kHz. Moreover, Table 1 shows an equivalent distribution of the degree of hearing loss in the right and left ears of the study group. The SRT and WRS coincided with the outcomes of pure-tone audiometry. In addition, both groups had bilateral type A tympanograms indicating normal middle ear pressure with preserved, elevated or absent acoustic reflexes in a match with the degree of hearing.

A fundamental objective of the current study was to measure the absolute hearing threshold as assessed by NB chirp stimuli and to estimate the mean difference between these electrophysiologic thresholds and the behavioral thresholds in adults who have normal hearing and different degrees of SNHL. The main measures obtained from wave V at 90 dB nHL (latency and amplitude) showed non-significant differences between the control group and subjects with mild and most those with moderate degrees of hearing loss. On the other hand, the measures in previous subjects were generally significantly different (shorter latency and larger amplitude) than subjects with moderately severe and severe degrees (Tables 2-5). Furthermore, the NB chirp-ABR thresholds in both ears exhibited a statistically significant increase from normal hearing up to higher degrees of hearing loss (Tables 2-5).

Hearing threshold assessed by NB chirp-ABR from right versus left ears revealed a statistically nonsignificant difference in the control group, rolling out the ear effect. Therefore, an additional analysis of the NB chirp-ABR hearing threshold was performed by ear. The correlation between the pure-tones or pure-tone averages threshold and the NB chirp ABR threshold was estimated. The best correlations with the ABR threshold for 0.5 kHz NB chirp were for 0.5 kHz, 1 kHz and 4 kHz; the highest was 0.5 kHz. The best correlations with the 1 kHz NB chirp ABR threshold were for 1 kHz,0.5 kHz and 4 kHz; the highest was 2 kHz. The best correlations with the 2 kHz NB chirp ABR threshold were for 2 kHz, 1 kHz and 0.5 kHz; the highest was 2 kHz. The best correlations with the 4 kHz NB chirp ABR threshold were for 4 kHz, 0.5 kHz and 8 kHz; the highest was 4 kHz.

The mean difference between the NB chirp-ABR threshold and the corresponding pure tone threshold (the highest correlate) showed an increase from normal hearing up to moderate hearing loss (in 0.5 kHz) or up to mild hearing loss (in 1-4 kHz) then the difference decreased again as the degree of hearing loss increased. These variations in mean difference were statistically significantly different in the 0.5 and 4 kHz frequencies and non-statistically significantly different in the 1 and 2 kHz frequencies (Tables 2-5).

Furthermore, studying the relationship between 0.5, 1, 2 and 4 kHz NB chirp-ABR and 0.5, 1, 2 and 4 kHz pure-tone hearing thresholds denoted positive correlations, respectively. Generally, these correlations were moderate-to-strong for normal hearing, mild SNHL, and moderately-severe SNHL but were weak for moderate and severe SNHL (Tables 2-5). Comparison between the outcomes of the four NB chirp ABR in the study group mostly revealed nonsignificant differences at different degrees of hearing loss (Table 6). Another important finding involved the predicted value of y (pure-tone threshold at 0.5, 1, 2 and 4 kHz) from x (0.5, 1, 2 and 4 kHz chirp-ABR threshold) using the regression equation in both groups as shown in Table 7. This table revealed a gradual increase in the correction value as the NB chirp-ABR hearing threshold increased which was marked for the 4 kHz then the 0.5 kHz especially when there was hearing loss (physiologic threshold ≥ 50 dB nHL).

Table (1): Distribution of degree of hearing loss in the study group.

Degree of hearing loss	Rt. Ear (N=50) No. of ears (%)	Lt. ear (N=50) No. of ears (%)	Total (N=100 ears) No. of ears (%)
Mild	10 (20%)	10 (20%)	20 (20%)
Moderate	11 (22%)	9 (18%)	20 (20%)
Moderately-severe	9 (18%)	10 (20%)	19 (19%)
Severe	10 (20%)	11 (22%)	21 (21%)
Profound	10 (20%)	10 (20%)	20 (20%)

Lt: Left; Rt: Right

Table (2): 0.5 kHz chirp-ABR measures, mean difference and correlation between 0.5 kHz chirp-ABR and 0.5 kHz pure-tone threshold in the control group and different degrees of hearing loss in the study group.

0.5 kHz chirp -ABR outcomes		CG	Degree of HL in SG mean±SD				F	*P*	Ordering*
			Mild	M	M-S	Severe			
Lat. of wave V (ms)	Rt.	5.31 ± 0.28	5.33 ± 0.18	5.30 ± 0.44	5.96 ± 0.94	6.27 ± 0.23	11.86	<0.001	a, a, a, b, b
	Lt.	5.32 ± 0.33	5.34 ± 0.18	5.52 ± 0.46	6.07 ± 0.87	6.05 ± 0.62	9.11	<0.001	a, a, a, b, b
Amp. of wave V (uV)	Rt.	0.41 ± 0.13	0.38 ±0.10	0.33 ± 0.18	0.29 ± 0.11	0.20 ± 0.09	4.99	0.001	a, ab, ab, bc, c
	Lt.	0.40 ± 0.14	0.37 ± 0.10	0.29 ± 0.13	0.31± 0.12	0.30 ± 0.19	2.15	0.08	a, ab, b, ab, a
0.5 kHz chirp-ABR thresholds (dB nHL)	Rt.	30.20 ± 2.25	54.00 ± 5.16	69.09 ± 8.31	74.44 ± 8.82	85.00 ± 5.48	367.21	<0.001	a, b, c, d, e
	Lt.	30.10 ± 1.59	54.00 ± 5.16	72.22 ± 6.67	78.00 ± 7.89	84.29 ± 7.87	32.33	<0.001	a, b, c, cd, de
0.5 kHz chirp-ABR	Mean± SD	17.79 ± 2.21	19.25 ± 4.38	24 ± 10.46	20.26 ± 5.13	17.31 ± 3.30	4.89	0.001	a, a, b, a, a

0.5 kHz chirp -ABR outcomes		CG	Degree of HL in SG mean±SD				F	P	Ordering*
			Mild	M	M-S	Severe			
and 0.5 kHz pure-tone threshold difference (dB)	95% CI	17.16-18.41	17.20-21.30	19.10-28.90	17.79-22.74	15.31-19.30			
	Range	10-27.50	15-30	15-60	10-35	10-20			
R		0.681	0.558	0.126	0.812	0.876	-		
P		<0.001	0.01	0.60	<0.001	<0.001			

* Ordering: Subgroups were given symbols (a, b, c, d or e; according to the number of subgroups). When they shared the same symbol, this meant that there was no difference between them while different symbol meant significant difference. ABR: auditory brainstem response; Amp.: Amplitude; CG: Control group; HL: Hearing loss; Lat.: Latency; Lt: Left, M: Moderate; M-S: Moderately-severe; Rt: Right; SG: Study group

Table (3): 1 kHz chirp-ABR measures, mean difference, and correlation between 1 kHz chirp-ABR and 1kHz pure-tone threshold in the control group and different degrees of hearing loss in the study group.

1 kHz chirp -ABR outcomes		CG	Degree of HL in SG mean±SD				F	p	Ordering *
			Mild	M	M-S	Severe			
Lat. of wave V (ms)	Rt.	5.24 ±0.43	5.39 ± 0.2 0	5.40 ± 0.65	5.87 ± 0.55	6.42 ± 0.13	14.61	<0.001	a, a, a, b, c
	Lt.	5.26 ± 0.37	5.43 ± 0.32	5.71 ± 0.47	5.67 ± 0.70	6.57 ± 0.42	15.97	<0.001	a, ab, b. b, c
Amp. of wave V (uV)	Rt.	0.48 ± 0.16	0.49 ± 0.10	0.45 ± 0.24	0.37 ± 0.16	0.17 ± 0.07	6.46	<0.001	a, a, a, a, b
	Lt.	0.49 ± 0.19	0.46 ± 0.14	0.34 ± 0.13	0.33 ± 0.17	0.24 ± 0.22	4.70	0.002	a, ab. Bc, bc, c
1 kHz chirp-ABR thresholds (dB nHL)	Rt.	30.10 ± 1.59	55.00 ± 5.27	70.00 ± 6.32	83.33 ± 7.07	87.50 ±7.07	619.61	<0.001	a, b, c, d, e
	Lt.	30.50 ± 2.53	54.00 ± 5.16	70.00 ± 7.07	81.00 ± 8.76	90.00 ± 0.00	533.42	<0.001	a, b, c, d, e
1 kHz chirp-ABR and 1 kHz pure-tone threshold difference (dB)	Mean± SD	18.00 ± 2.11	19.50 ± 3.94	18.00 ± 9.09	16.05 ± 6.14	16.67 ± 5.23	1.69	0.16	
	95% CI	17.40-18.60	17.66-21.34	13.75-22.25	13.09-19.01	13.77-19.56			
	Range	15-25	15-30	0.00-35	0.00-25	5.25			
r		0.608	0.674	0.068	0.641	0.425			
p		<0.001	0.001	0.78	0.003	0.11			

* Ordering: Subgroups were given symbols (a, b, c, d or e; according to the number of subgroups). When they shared the same symbol, this meant that there was no difference between them while different symbol meant significant difference. ABR: auditory brainstem response; Amp.: Amplitude; CG: Control group; HL: Hearing loss; Lat.: Latency; Lt: Left, M: Moderate; M-S: Moderately-severe; Rt: Right; SG: Study group

Table (4): 2 kHz chirp-ABR measures, mean difference, and correlation between 2 kHz chirp-ABR and 2 kHz pure-tone threshold in the control group and different degrees of hearing loss in the study group.

2 kHz chirp -ABR outcomes		CG	Degree of HL in SG mean±SD				F	p	Ordering*
			Mild	M	M-S	Severe			
Lat. of wave V (ms)	Rt.	5.26 ± 0.33	5.37 ± 0.20	5.31 ± 0.82	5.71 ± 0.52	6.23 ± 0.60	7.39	<0.001	a, ab, ac, bc, d
	Lt.	5.33 ± 0.34	5.38 ± 0.12	5.65 ± 0.75	5.91 ± 0.63	6.32 ± 0.75	9.50	<0.001	a, a, ab, bc, c
Amp. of wave V (uV)	Rt.	0.53 ± 0.17	0.49 ± 0.06	0.49 ± 0.19	0.37 ± 0.19	0.18 ± 0.10	7.42	<0.001	a, ab, ac, bc, d
	Lt.	0.49 ± 0.16	0.48 ± 0.05	0.44 ± 0.20	0.40 ± 0.32	0.25 ± 0.14	3.16	0.02	a, a, a, a, b
2 kHz chirp-ABR thresholds (dB nHL)	Rt.	29.70 ± 1.57	54.00 ± 5.16	68.18 ± 6.03	87.50 ± 4.63	86.67 ± 8.16	711.45	<0.001	a, b, c, d, de
	Lt.	29.70 ±1.77	55.00 ± 7.07	70.00 ± 10	85.00 ± 7.07	90.00 ± 0.00	529.75	<0.001	a, b, c, d, e
2 kHz chirp-ABR and 2 kHz pure-tone threshold difference (dB)	Mean± SD	17.34 ± 2.23	18.50 ± 5.40	14.50 ± 10.25	16.94 ± 4.58	16.15 ± 7.68	1.22	0.31	
	95% CI	16.70-17.97	15.97-21.03	9.70-19.30	14.67-19.22	11.51-20.79			
	Range	7.50-25	10.35	5-35	5-25	5-25			
r		0.656	0.506	0.160	0.712	0.184	-		
p		<0.001	0.02	0.50	0.001	0.55			

* Ordering: Subgroups were given symbols (a, b, c, d or e; according to the number of subgroups). When they shared the same symbol, this meant that there was no difference between them while different symbol meant significant difference. ABR: auditory brainstem response; Amp.: Amplitude; CG: Control group; HL: Hearing loss; Lat.: Latency; Lt: Left, M: Moderate; M-S: Moderately-severe; Rt: Right; SG: Study group

Table (5): 4 kHz chirp-ABR measures, mean difference and correlation between 4 kHz chirp-ABR and 4kHz pure-tone threshold in the control group and different degrees of hearing loss in the study group.

4 kHz chirp -ABR outcomes		CG	Degree of HL in SG mean±SD				F	P	Ordering*
			Mild	M	M-S	Severe			
Lat. of wave V (ms)	Rt.	5.16 ± 0.04	5.32 ± 0.07	5.53 ± 0.17	5.63 ± 0.16	6.32 ± 0.10	20.19	<0.001	a, ab, b, b, c
	Lt.	5.19 ± 0.31	5.31 ± 0.17	5.57 ± 0.47	5.91 ± 0.59	6.29 ± 0.46	20.76	<0.001	a, ab, b, c, d
Amp. of wave V (uV)	Rt.	0.45 ± 0.02	0.43 ± 0.03	0.48 ± 0.06	0.31 ± 0.05	0.19 ± 0.02	5.84	<0.001	a, ab, a, bc, c
	Lt.	0.42 ± 0.12	0.44 ± 0.09	0.49 ± 0.21	0.41 ± 0.29	0.19 ± 0.07	4.66	0.002	a, a, a, a, b
4 kHz chirp-ABR thresholds (dB nHL)	Rt.	29.70 ± 0.22	57.00 ± 2.13	68.18 ± 2.26	87.14 ± 1.84	86.67 ± 3.33	523.44	<0.001	a, b, c, d, d
	Lt.	29.70 ± 1.57	58.00 ± 7.89	67.78 ± 8.33	81.00 ± 8.76	86.25 ± 7.44	388.63	<0.001	a, b, c, d, e
4 kHz chirp-ABR and 4 threshold difference (dB)	Mean± SD	17.06 ± 2.14	21.66 ± 6.45	18.05 ± 7.71	18.14 ± 7.12	13.01 ± 7.39	5.09	0.001	a, b, a, ab, c
	95% CI	16.45-17.67	18.64-24.68	14.44-21.66	14.48-21.81	8.74-17.27			
	Range	7.50-20	11.20-33.70	3.70-32.50	3.70-25	3.80-20			
r		0.554	0.456	0.329	0.424	0.210	-		
P		<0.001	0.04	0.16	0.09	0.47			

* Ordering: Subgroups were given symbols (a, b, c, d or e; according to the number of subgroups). When they shared the same symbol, this meant that there was no difference between them while different symbol meant significant difference. ABR: auditory brainstem response; Amp.: Amplitude; CG: Control group; HL: Hearing loss; Lat.: Latency; Lt: Left, M: Moderate; M-S: Moderately-severe; Rt: Right; SG: Study group

Table (6): Comparison between outcomes of different NB chirp-ABR at different degree of hearing loss in the study group.

NB chirp-ABR measurements		Degree of HL F(*p*)			
		Mild	M	M-S	Severe
Lat. of wave V (ms)	Rt.	0.32 (0.87)	0.41 (0.80)	0.43 (0.78)	1.67 (0.19)
	Lt.	0.91 (0.46)	0.18 (0.95)	0.51 (0.73)	1.60 (0.20)
Amp. of wave V (uV)	Rt.	2.39 (0.07)	1.19 (0.33)	1.77 (0.16)	0.73 (0.58)
	Lt.	1.59 (0.19)	1.10 (0.11)	0.41 (0.80)	0.10 (0.42)
NB chirp-ABR threshold (dB nHL)	Rt.	0.55 (0.70)	0.24 (0.91)	7.04 (<0.001)	0.10 (0.98)
	Lt.	0.73 (0.58)	0.35 (0.84)	1.33 (0.27)	1.48 (0.23)
Mean chirp-ABR & pure-tone threshold difference	Combined	1.50 (0.21)	3.29 (0.01)	1.57 (0.19)	1.57 (0.19)

Amp.: Amplitude; CG: Control group; HL: Hearing loss; Lat.: Latency; Lt: Left, M: Moderate; M-S: Moderately-severe; NB chirp-ABR: Narrow-Band chirp-auditory brainstem response; Rt: Right

Table (7): Predicted value of the best correlated pure-tone threshold (y) from the NB chirp-ABR threshold (x) using regression equation in both groups.

NB chirp-ABR threshold (X) (dB nHL)	Predicted PT threshold (Correction value for y from x)			
	0.5 kHz	1 kHz	2 kHz	4 kHz
Regression equation	y = -15.66 + (0.92*x)	y = -18.19 + (0.98*x)	y = -16.13 + (0.97*x)	y = 10.49 + (0.79*x)
In control group				
20	2.74 (-17.26)	1.41 (-18.59)	3.27 (-16.73)	5.31 (-14.69)
25	7.34 (-17.66)	6.31 (-18.69)	8.12 (-16.88)	9.26 (-15.74)
30	11.94 (-18.06)	11.21 (-18.79)	12.97 (-17.03)	13.21 (-16.79)
35	16.54 (-18.46)	16.11 (-18.89)	17.82 (-17.18)	17.16 (-17.84)
40	21.14 (-18.86)	21.01 (-18.99)	22.67 (-17.33)	21.11 (-18.89)
In study group				
50	30.34 (-19.66)	30.81 (-19.19)	32.37 (-17.63)	29.01 (-20.99)
60	39.54 (-20.46)	40.61 (-19.39)	42.07 (-17.93)	36.91 (-23.09)
70	48.74 (-21.26)	50.41 (-19.59)	51.77 (-18.23)	44.81 (-25.019)
80	57.94 (-22.06)	60.21 (-19.79)	61.47 (-18.53)	52.71 (-27.29)
90	67.14 (-22.86)	70.01 (-19.99)	71.17 (-18.83)	60.61 (-29.39)

HL: hearing loss; NB chirp-ABR: Narrow-Band chirp-auditory brainstem response; PT: pure tone

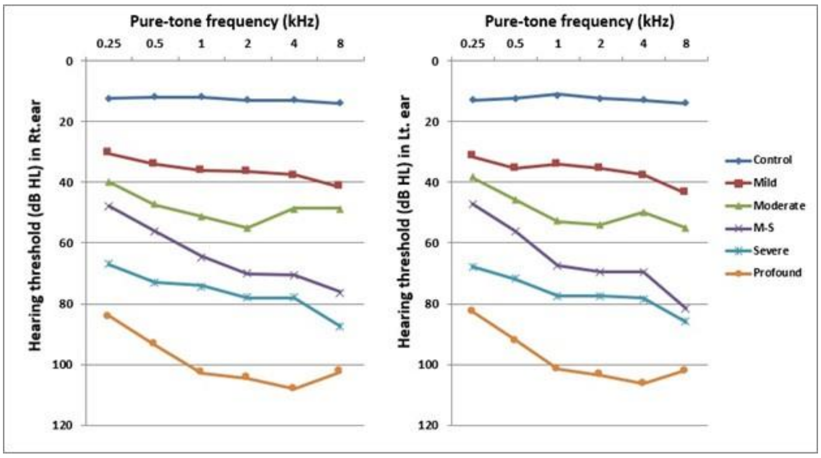

Figure 1: Mean pure-tone hearing threshold in both ears of the control and study groups.

DISCUSSION

The purpose of this study was to determine the ability of the four types of NB chirp ABR (0.5, 1, 2 and 4kHz) to estimate the hearing threshold and to find the effect of hearing level on the mean difference between the electrophysiologic and behavioral thresholds in normal hearing and different degrees of SNHL. At the start, chirp stimuli were presented at 90 dB nHL. Wave V latency and amplitude at this level were comparable among normal hearing, mild and moderate SNHL but were significantly different with shorter latency and larger amplitude than the moderately severe and severe degrees. This could be related to the extent of cochlear damage that is limited in earlier degrees of SNHL but becomes extensive in more severe losses causing a delay in neural conduction time and reduced response strength [14].

Wave V was then traced down to a threshold that coincided with the behavioral threshold of the corresponding pure-tone in agreement with the accuracy and frequency specificity of tone-burst evoked ABR [15]. The mean difference between NB chirp ABR (0.5, 1, 2 and 4 kHz) and corresponding pure-tone thresholds were 18.05±3.04, 18.90±2.38, 17.00±3.07 and 16.71±2.84 dB, respectively in the control group. These results closely matched those of El Kousht et al. [16] who studied NB chirp-ABR in 40 adults (80 ears) with an age range of 19-50 years that were arranged into 20 ears with normal hearing sensitivity and 60 ears with different degrees of SNHL. They reported that the mean differences were 19.5±3.2, 21.3±3.2, 19.3±3.2 and 19.8±4.4, respectively in the normal hearing group.

Actual differences between the NB chirp-ABR and related pure-tone thresholds increased from normal hearing up to a moderate hearing loss in 0.5 kHz and up to a mild hearing loss in 1-4 kHz, then the difference reduced as the degree of hearing loss increased; this is consistent with Ozdek et al. [17], who assessed the Auditory steady state responses (ASSR) threshold in 23 normal hearing adults and 38 adults with hearing loss, using a modulation rate of 46 Hz, amplitude modulation of 100%, and frequency variation of 10%. They reported an increase in the accuracy of hearing loss estimation by ASSR with increasing the severity of hearing loss that could be attributed to the electrophysiological recruitment phenomenon as the damage of the outer hair cells causes a compensatory increase in the amplitude of near-threshold afferent responses providing gain at low levels [18].

Another purpose was to study the relationships between the NB chirp-ABR and behavioral hearing thresholds that were positive for moderate-to-strong for normal hearing, mild SNHL and moderately-severe SNHL but weak positive for moderate and severe SNHL. The relationship between 0.5, 1, 2, 4 kHz NB chirp ABR and 0.5, 1, 2, 4 kHz pure tone thresholds was also studied by El Kousht et al. [16] who reported a strong positive electrophysiologic-behavioral correlation in adults with different degrees of SNHL.

Furthermore, the outcomes of the four NB chirp-ABR in the study group were mostly comparable at different degrees of hearing loss which indicates the consistency of latency, amplitude, threshold estimation and mean electrophysiologic-behavioral difference across the four assessments. Therefore, using NB chirp-ABR in hearing evaluation turns out to be easy and reliable.

Another method to estimate the hearing threshold is the prediction of the behavioral hearing threshold from the electrophysiologic one using NB chirp-ABR. A regression analysis was performed on the outcomes of normal hearing adults and provided regression equations to predict the value of y (pure-tone threshold at 0.5, 1, 2 and 4 kHz) from x (0.5, 1, 2 and 4 kHz chirp-ABR threshold) in both groups. The correction value increases gradually when the NB chirp-ABR's hearing threshold has increased, which is higher for the 4 kHz then the 0.5 kHz, especially when the electrophysiologic threshold is ≥ 50 dB nHL. Our findings coincide with what Baldwin and Watkin reported [19]. They used a linear regression model to predict the pure-tone threshold from click-evoked ABR thresholds in 92 children with permanent childhood hearing impairment. The ABR was performed less than six months, while pure-tone audiometry was completed at 2.6 to 12.8 years. The authors found a strong positive correlation between ABR threshold and pure-tone average 2-4 kHz and also estimated a regression equation of $y = -1.32 + 0.94{*}x$ to predict the behavioral threshold of pure-tone average 2–4 kHz from ABR threshold. They concluded that click ABR may overestimate future hearing loss in infants who have suffered perinatal insult or are prematurely born; this could be attributed to an unidentified temporary conductive hearing loss or a neural component and both require adequate assessment test battery. On the other hand, no previous research predicted the behavioral hearing threshold using NB-chirp ABR. The current findings provide evidence to suggest that ABR recording in response to NB-chirps can be an efficient tool for estimating hearing thresholds in adults with normal hearing and those suffering from SNHL. Therefore, these electrophysiologic measures could provide an easy and rapid frequency-specific threshold estimation in young children and subjects difficult to test with considerable accuracy.

Conclusions: This study has shown that the NB chirp-ABR has the potential to accurately estimate the electrophysiologic hearing threshold in adults with normal hearing and those with SNHL of variable degrees. The mean difference between the NB chirp-ABR and the related pure-tone hearing thresholds at 0.5, 1, 2 and 4 kHz was found to be 18.05±3.04, 18.90±2.38, 17.00±3.07 and 16.71±2.84, respectively that has been supported by previous studies. The relationship between the electrophysiologic and behavioral hearing thresholds becomes weaker at higher degrees of SNHL. In addition, the value of y (pure-tone threshold at 0.5, 1, 2 and 4 kHz) was predicted from x (0.5, 1, 2 and 4 kHz chirp-ABR threshold) using regression equations with an increase in correction value as NB chirp- ABR hearing threshold increases mainly for the 4 kHz then for the 0.5 kHz. These outcomes have indicated that NB chirp-ABR can provide an easy and rapid frequency-specific threshold estimation in normal-hearing and different degrees SNHL. Consequently, it is suggested for threshold estimation in very young children and difficult-to-test subjects.

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