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Original Article

Auditory brainstem-evoked response to chirp and click stimuli in children with moderate and severe sensorineural hearing loss

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Abstract

Background

Auditory brainstem response (ABR) using click stimuli enables global objective estimation of hearing threshold. The application of chirp stimuli aims to produce synchronized response from large portion of hair cells in the basilar membrane. The chirp was designed to produce simultaneous displacement maxima along the cochlear partition by compensating for frequency-dependent traveling-time differences.

Objectives

The study aimed to compare the response characteristic of both clicks and chirps stimuli in children. Accordingly, we compared latency and amplitude of wave V at different intensity levels and waves I and III at high levels. Moreover, we correlate between pure-tone audiometry (PTA) threshold and each of click and chirp ABR threshold in the same groups.

Patients and methods

This study included two groups: the control group (G1) consisted of 30 children with normal peripheral hearing. A study group (G2) consisted of 60 children with moderate to severe sensorineural hearing loss.

Results

The results have shown that on using chirp stimuli wave V could be detected easier with shorter latency and larger amplitude than in click ABR. On the other hand, click stimulus was better than chirp stimulus at high-intensity levels regarding identification of waves I and III. In addition, there are significant correlations between chirp and behavioral PTA. Moreover, there are significant correlations between click and behavioral PTA in normal hearing and hearing-impaired children except at severe steeping sensorineural hearing loss.

Keywords: Auditory brainstem response, children with sensorineural hearing loss, chirp, click auditory brainstem response

Introduction

Auditory brainstem response (ABR) is the most popular and precise method for hearing impairment detection [1,2]. Click auditory brainstem response (C-ABR) has an abrupt and rapid onset with broad spectrum, no frequency-specific response. C-ABR needs good neural synchrony and a greater number of neurons that fire results in a larger response amplitude [2]. In C-ABR the cochlear traveling wave takes some time to reach from the base of the cochlea to its apical end. Therefore, the activity of the different neural units along the cochlear partition will not be stimulated at the same time and the neural activity across all nerve fibers will be smeared [3–5]. Chirp stimulus aims at input compensation in auditory method using a stimulus which delays the input of the higher frequency components of the click stimulus relative to the lower frequencies. Therefore, the arrival of each frequency component at its place of maximum excitation along the

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cochlear partition is delayed. Accordingly, all components arrive at approximately the same time. Higher temporal synchronization of the elements that contribute to the evoked response is achieved and a larger amplitude ABR is produced [6]. In this study, we compared between click and chirp ABR latencies and amplitude in normal hearing children and children with both moderate and severe sensory neural hearing loss.

Patients and Methods

A total number of 90 children in the age range of 6–12 years were included. The control group (G1) consisted of 30 patients with bilateral normal peripheral hearing. The study group consisted of 60 patients, who were divided into two subgroups: 30 patients with moderate (M) sensorineural hearing loss (SNHL) (G2-M) and 30 patients with severe (S) SNHL (G2-S). This subgroup (G2-S) was divided into two subgroups; 20 patients with flat audiometric (G2-Sf) configuration pattern and 10 patients with steeping audiometric configuration pattern (G2-Ss). All children were tested in a sound-treated room model no RE 24, acoustic immittance meter model Interacoustics AZ26 with a probe tone of 220 Hz, pure-tone audiometer (PTA) Interacoustics model AC40 with headphones TDH39 and bone vibrator B71 and auditory-evoked potentials model Interacoustics Eclips 25. All of them were subjected to carful history taking, full audiological history, basic audiological evaluation including PTA for both air conduction (for the frequency range, 250–8000 Hz) and bone conduction (for the frequency range, 500–4000 Hz), speech audiometry including immittancemetry and ABR. Click and chirp ABR stimuli were used and tested at 0.5, 1, 4 kHz). Stimuli were presented monaurally to each ear via an ER-3A insert phone, with a repetition rate (RR) of 21.1/s for click and 44/s, 35/s for chirp. Alternating polarity, 1000 sweeps for C-ABR stimulus, and 2000 sweeps for chirp ABR stimulus, the recording window is 1–14 ms and the filtering system was 150–3000 Hz for both C-ABR and chirp ABR.

Statistical analysis

Simple descriptive statistics were performed in order to calculate numerical parametric data as mean, SD, and minimum and maximum of range while they were done for categorical data as number and percentage. Inferential analyses were done for quantitative variables using paired *Z*-test in case of two independent groups with parametric data. The level of significance at a *P* value of less than 0.05 was considered significant, and a *P* value of less than 0.01 is highly significant; otherwise it is nonsignificant (Fig. 1).

Results

Results of the study will be presented as follows:

Comparison of waves I, III, and V latency and amplitude between C-ABR and chirp stimuli (44 and 35 RR) of all tested groups.

Discussion

Wave latency

Latency of wave V

In all groups of the current study, regardless of the stimulus type, the mean wave V latencies were longer as intensity

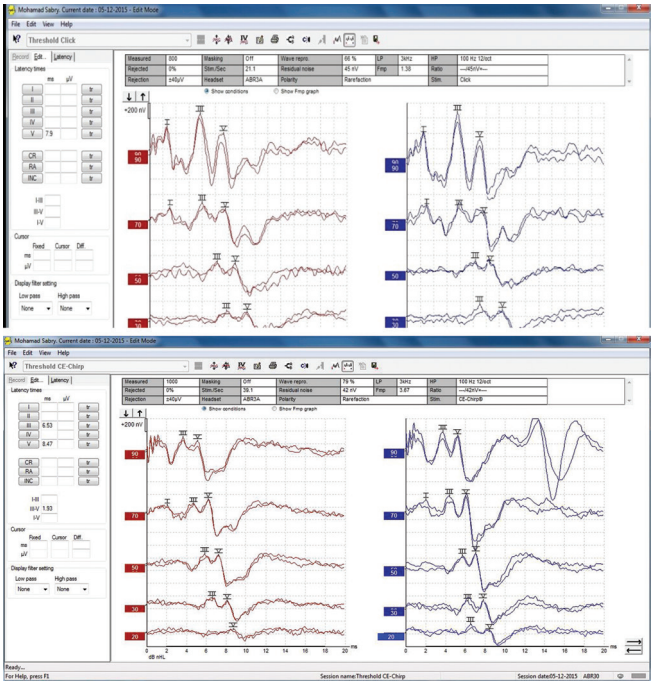

Figure 1: Click and chirp-evoked ABR responses for normal hearing child (right and left ears). ABR, auditory brainstem response.

Table 1: The comparison of wave V latency (ms) at different intensity levels between chirp 44 repetition rate versus click auditory brainstem response in all tested groups

Latency (G1)	Chirp 44 RR (mean±SD)	Click ABR (mean±SD)	*Z* value	*P*
Wave V 90 dBnHL	5.006±0.485	5.27±0.259	−3.31	0.001**
Wave V 70 dBnHL	5.458±1.045	5.711±0.308	−0.2.17	0.003**
Wave V 50 dBnHL	6.340±0.467	6.560±0.451	−3.16	0.002**
Wave V 30 dBnHL	7.235±0.706	7.584±0.395	−3.80	0.000**
Latency (G2-M)				
Wave V 90 dBnHL	4.92±0.46	5.48±0.32	−5.59	0.000**
Wave V 70 dBnHL	5.74±0.51	6.03±0.43	−3.33	0.001**
Wave V 60 dBnHL	6.27±0.76	6.57±0.74	−5.36	0.003**
Wave V 50 dBnHL	6.73±0.83			
Latency (G2-Sf)				
Wave V 90 dBnHL	5.12±0.58	5.75±0.339	−3.77	0.000**
Wave V 80 dBnHL	5.91±0.34	6.07±0.585	−1.633	0.102
Wave V 70 dBnHL	6.44±0.457			
Wave V 60 dBnHL				
Latency (G2-Ss)				
Wave V 90 dBnHL	4.97±0.49	5.42±0.469	−3.76	0.000**
Wave V 80 dBnHL	5.73±0.87	5.88±1.24	−1.63	0.87
Wave V 70 dBnHL	6.47±0.922			
Wave V 60 dBnHL	7.37±1.11			

ABR, auditory brainstem response; RR, repetition rate.**Highly statistically significant difference.

decreased (Table 1). In the control group, G1, the analysis of wave V latency with both click and CE-chirp stimuli at intensity levels 90, 70, 50, and 30 dBnHL revealed a highly statistically significant shorter wave V latencies provoked by CE-chirp compared with click stimuli. This finding agrees with Kristensen and Elberling [7] and Maloff and Hood [8]. They reported that the chirps give shorter detection time and higher signal-to-noise ratio than the click. The results indicate that a chirp is a more efficient stimulus than a click for the recording of auditory-evoked responses in normal-hearing patients using transient sounds. In addition, this finding agrees with Elberling and Don [9], who reported that the latencies obtained with the CE-chirp stimulus are shorter than those obtained with click. The CE-chirp was developed to simultaneously stimulate different regions of the basilar membrane (BM) and compensate for the sound travel time in the cochlea. Accordingly, low-frequency components are presented before the high-frequency components, that is, before the zero latency reference, in such a way that shorter latencies in response to this stimulus are expected. On the other hand, this finding disagrees with Rodrigues and Lewis [10]. They reported that click latencies were shorter than those obtained with the CE-chirp stimulus at 80, 60, 40, and 20 dBnHL.

The study subgroup, G2-M, showed a highly statistically significant shorter wave V latencies provoked by CE-chirp compared with click stimuli at 90, 70, and 60 dBnHL levels, while at 50 dBnHL (close to behavioral threshold), there were no valid cases of wave V provoked by click stimuli to perform the comparison. This means that chirp ABR thresholds were closer to behavioral thresholds and better than clicks in ears with moderate SNHL [8].

The study subgroup G2-Sf showed that CE-chirp stimuli presented wave V latencies significantly shorter than those observed with clicks only at the intensity level 90 dBnHL. While at 80 dBnHL, wave V presented no statistically significant difference in latencies between CE-chirp and click stimuli. On the other hand, at 60 and 70 dBnHL there were no valid cases of wave V on using C-ABR stimulus to perform a comparison with CE-chirp. This finding agrees with Torsten *et al.* [11]; Maloff and Hood [8], who demonstrated that at the highest levels of stimulation with chirp, the early low-frequency energy of the chirp probably stimulates basal regions of the BM due to upward spread of excitation and produces synchronous discharges of VIII (8^{th}) -nerve fibers along the length of the human cochlear partitions. Otherwise, neural response to chirps at lower intensity levels is mainly dominated by lower frequency cochlear regions, which are characterized by longer latencies.

For the study subgroup G2-Ss, the CE-chirp stimuli showed wave V latencies shorter than those observed with clicks only at an intensity level of 90 dBnHL, while at 80 dBnHL, there were no statistically significant differences in wave V latencies between CE-chirp and click stimuli. In addition, at 70 and 60 dBnHL, CE-chirp findings could not be compared with click as there were no valid cases of wave V on using C-ABR. This could be explained by the fact that in steeping hearing loss, the neural remnants were better at apical areas of the cochlea. This indicates the ability of the chirp stimuli to get used to the neural charges of the apical areas allowing better production of the waveforms. This concept agrees with Maloff and Hood [8], and Elberling *et al.* [6].

Latency of waves I and III

In all groups of the current study, regardless of the stimulus type, waves I and III latencies were analyzed at high-intensity levels (90 dBnHL) (Table 2). The control group G1 showed no statistically significant differences between click and chirp stimuli as regards waves I and III latency. These finding agree with Torsten *et al.* [11] who reported that at the highest stimulation level typical early peaks are nearly similar in their responses to the click as well as to the broadband chirp. In the same study they reported that the broadband chirp did not show clear earlier peaks I–III. They referred this to biased frequency representations at the level of the neural generators for waves I and III, while the generator for wave V probably has a flatter frequency response.

The subgroup G2-M showed there was no statistically significant differences between click and CE-chirp stimuli as regards wave I latency at 90 dBnHL level. These findings agree with Torsten *et al.* [11]. On the other hand, there was a highly statistically significant shorter latency of wave III on using CE-chirp than click stimuli. The explanation may be that hearing loss had its effect on the generator of wave I and it causes latency shift of wave I on using CE-chirp stimuli. These findings agree with Cebulla *et al.* [12].

The results of subgroup G2-Sf showed no statistically significant differences between click and CE-chirp stimuli as regards latency of waves I and III when presented at 90 dBnHL, while in the subgroup G2-Ss, the results showed a highly statistically significant shorter latency as regards waves I and III on using CE-chirp than click stimuli.

Table 2: Comparison of waves I and III latency (ms) at 90 dBnHL between chirp 44 repetition rate versus click auditory brainstem response in all tested groups

Latency (G1)	Chirp 44 RR (mean±SD)	Click ABR (mean±SD)	*Z* value	*P*
Wave I 90 dBnHL	1.4±0.488	1.354±0.154	−1.74	0.81
Wave III 90 dBnHL	3.486±0.827	3.632±1.362	−0.955	0.34
Latency (G2-M)				
Wave I 90 dBnHL	1.44±0.20	1.48±0.18	−1.09	0.27
Wave III 90 dBnHL	3.35±0.366	3.62±0.20	−4.09	0.000**
Latency (G2-Sf)				
Wave I 90 dBnHL	1.61±0.293	1.50±0.21	−1.214	0.225
Wave III 90 dBnHL	3.32±0.586	3.411±0.444	−1.262	0.207
Latency (G2-Ss)				
Wave I 90 dBnHL	1.41±0.253	1.81±0.596	−3.28	0.002**
Wave III 90 dBnHL	3.27±0.405	3.84±0.293	−3.34	0.001**

ABR, auditory brainstem response; RR, repetition rate.**Highly statistically significant difference.

The detection of early waves subsequently helps in diagnosing the type of hearing loss by allowing the calculation of waves I–III, III–V, and I–V IPL, which are useful to determine conductive hearing loss or the central causes of hearing loss [13].

Wave amplitude

Wave V amplitude

In the current study, the results of group G1 showed that the average amplitudes of wave V with the CE-chirp stimulus were significantly larger than those recorded with click stimulus at all intensity levels (90, 70, 50, and 30 dBnHL) (Table 3). Our findings agree with Cebulla *et al.* [12], who reported significantly higher amplitudes of wave V responses on using chirp-evoked ABR than click-evoked ABR. They concluded that significantly better synchronized excitation of the cochlea can be achieved with chirp stimuli than with conventional click stimuli. This leads to an optimal temporal representation of individual responses from different frequency ranges.

Moreover, Cebulla *et al.* [3,12] reported that the best advantage of CE-chirp stimuli is providing larger amplitude ABRs. This helps in detecting thresholds in a faster and easier way, at low intensity levels, when performing neonatal screening or frequency-specific testing. Moreover, they considered it faster and more reliable during ASSR acquisition, especially close to the threshold.

On the other hand, the results of the current study did not agree with Rodrigues and Lewis [10], who demonstrated smaller wave amplitudes for chirp stimuli when compared with click at a high-intensity level (80 dBnHL). The larger amplitude of chirp was found at low intensity levels (60, 40, and 20 dBnHL). They recommended not using chirp at high-intensity levels. They explained that at high intensities, there are mechanical factors when stimulating the cochlea that make the chirp even worse than the traditional stimulus [14]. This is in contrast to the current research outcome. Our results indicate that at high-intensity levels, chirp produced better amplitude outcome.

Table 3: Comparison of V amplitude (μv) between chirp 44 repetition rate versus click auditory brainstem response in all tested groups

Amplitude (G1)	Chirp 44 RR (mean±SD)	Click ABR (mean±SD)	*Z* value	*P*
Wave V 90 dBnHL	0.869±250.764	0.567±172.851	−5.68	0.000**
Wave V 70 dBnHL	0.751±252.943	0.463±145.155	−5.97	0.000**
Wave V 50 dBnHL	0.583±194.858	0.380.±160.845	−5.18	0.000**
Wave V 30 dBnHL	0.426.±173.249	0.285±133.137	−4.24	0.000**
Amplitude (G2-M)				
Wave V 90 dBnHL	0.605±271.88	0.407±160.09	−4.704	0.000**
Wave V 70 dBnHL	0.399±168.81	0.305±139.9	−3.318	0.001**
Wave V 60 dBnHL	0.214±139	0.200±139	−0.853	0.394
Wave V 50 dBnHL	0.158±84.99			
Amplitude (G2-Sf)				
Wave V 90 dBnHL	0.612.5±0.278	0.364.±0.163	−4.50	0.000**
Wave V 80 dBnHL	0.381±0.167	0.292.±0.979	−3.312	0.001**
Wave V 70 dBnHL	0.245±0.126			
Wave V 60 dBnHL				
Amplitude (G2-Sf)				
Wave V 90 dBnHL	0.498±0.187	0.347±0.149	−2.833	0.004**
Wave V 80 dBnHL	0.310±0.157	0.265±0.122	−1.539	0.124
Wave V 70 dBnHL	0.191±0.120			
Wave V 60 dBnHL	0.125±0.106			

ABR, auditory brainstem response; RR, repetition rate.**Highly statistically significant difference.

In the study subgroup G2-M, the amplitudes of wave V obtained with the CE-chirp stimulus were found to be significantly larger than those obtained with click at intensities 90 and 70 dBnHL. On the other hand, at 60 dBnHL, there were no significant differences in amplitude between both stimuli, while at 50 dBnHL, CE-chirp could not be compared with click as there were no valid cases of wave V on using C-ABR outcome. This agreed with Maloff and Hood [8] and Cebulla *et al.* [12] who explained that increased temporal synchrony of a chirp generates better waveform at high-intensity levels. On the other hand, the results of the current study disagree with Elberling and Don [9], who reported that at high levels the chirp ABR amplitude decreases. They speculated that at low levels, each frequency component of a chirp excites a restricted location in the cochlea, but for higher levels there is an upward spread of excitation. Stimulation of a broader area of the cochlea affects the synchronization with considerable spectral splatter resulting in reduced amplitude response. The authors suggested that newer machines have better ability for adjusting the input delay time to get better synchronized amplitude results.

The study subgroups G2-Sf and G2-Ss continued to show that the amplitude of wave V obtained with the CE-chirp stimulus were significantly larger than those obtained with clicks at 90 and 80 dBnHL in the subgroup G2-Sf. This finding agrees with Maloff and Hood [8] and Cebulla *et al*. [12]. On the other hand, at 80 dBnHL the study subgroup G2-Ss, could not show a statistically significant difference between clicks and CE-chirp stimuli due to the reduced number of valid wave V traces.

Similar to the explanation of latency, the amplitude statistical comparison in G2-Sf and G2-Ss subgroups could not be completed because of the difference in threshold detectability that was more favorable in chirp compared with click. In other words, wave V was closed to behavior threshold of PTA on using CE-chirp than C-ABR. This indicates better outcome with the chirp stimulus which may be referred to the ability of chirp stimuli to stimulate the apical portion of the cochlea in case of severe hearing loss with better threshold determination. This speculation should be further evaluated in other research works.

Wave 1 and III amplitude

In all groups of the current study, regardless of the stimulus type, waves I and III amplitudes were analyzed at 90 dBnHL (Table 4). The amplitude of waves I and III in click stimuli were significantly larger than those observed with CE-chirp stimuli in G1 and G2-M groups. This finding is consistent with Elberling *et al*. [15]. They stated that to improve the chirp stimulus design, waves I and III could be absent. Accordingly,

Table 4: Comparison of waves I and III amplitude (μv) at 90 dBnHL between chirp 44 repetition rate versus click auditory brainstem response in all tested groups

Amplitude (G1)	Chirp 44 RR (mean±SD)	Click ABR (mean±SD)	*Z* value	*P*
Wave I 90 dBnHL	0.207±0.121	0.319±0.151	−3.32	0.001**
Wave III 90 dBnHL	0.300±0.142	0.400±0.153	−5.45	0.000**
Amplitude (G2-M)				
Wave I 90 dBnHL	0.092±69.14	0.207±0.110	−2.87	0.004*
Wave III 90 dBnHL	0.155±93.79	0.266±0.112	−3.44	0.001*
Amplitude (G2-Sf)				
Wave I 90 dBnHL	0.142±121.75	0.190±0.135	−2.20	0.028
Wave III 90 dBnHL	0.185±121.62	0.247±0.126	−1.29	0.196
Amplitude (G2-Ss)				
Wave I 90 dBnHL	0.142.±0.687	0.157±0.878	−2.060	0.039
Wave III 90 dBnHL	0.192.±0.718	0.190±0.9787	−0.153	0.878

ABR, auditory brainstem response; RR, repetition rate.**Highly statistically significant difference.

waves I and III amplitudes were smaller than those for the corresponding click stimuli ABR at the same intensity level.

The amplitude analysis of wave I and III in subgroup G2-Sf and G2-Ss showed nonsignificantly larger amplitude results obtained with the click stimuli than those obtained with CE-chirp stimulus at 90 dBnHL. In the current research, severe degrees of hearing loss may be reflected on the amplitude of early ABR waves. This finding agrees with Musiek and Baran [16]. They reported that with severe degrees of hearing loss the resultant dysfunction affects the appropriate compression of BM movement for high-intensity stimuli.

Waveform detectability in all study groups

Detectability of wave V

Wave V was (100%) detectable at all tested ears in G1 (Table 5). This occurred when the presence/absence of waves V was analyzed at 90, 70, 50, and 30 dBnHL on using either CE-chirp or click. In both G2-M and G2-S, wave V was detectable in all tested ears, wave V detectability was better when using CE-chirp stimulation than with click stimuli This agrees with Cebulla *et al*. [12]. They demonstrated that wave V was always identifiable when using 60 dBnHL stimulus level (100%). At 40 dBnHL wave V was reliably recognizable in 95% of the click-evoked ABR and in 100% of the chirp-evoked ABR in neonates.

G2-Sf showed detectable wave V in 82.5% when using click stimuli. This percentage improved to 100% upon using chirp stimuli at the same used stimulation level. When reducing intensity levels till obtaining threshold, wave V detectability was better for CE-chirp stimuli at 70 dBnHL than click stimuli (41.5% with chirp 44 RR and 39% with chirp 35 RR, and only 5% with click), while there was no identifiable wave V at 60 dBnHL for all stimuli. This result emphasized that absence of ABR waves at high-intensity levels with click does not necessarily imply total deafness. It is well known that C-ABR threshold represents hearing in the 2–4 kHz and is dependent on the mean threshold of both latencies [17].

Table 5: Detectability of wave V in all tested groups

G1	Click (%)	Chirp 44 RR (%)	Chirp 35 RR (%)
Detectability of wave V at 90 dBnHL	100	100	100
Detectability of wave V at 70 dBnHL	100	100	100
Detectability of wave V at 50 dBnHL	100	100	100
Detectability of wave V at 30 dBnHL	100	100	100
G2-M			
Detectability of wave V at 90 dBnHL	100	100	100
Detectability of wave V at 70 dBnHL	100	100	100
Detectability of wave V at 60 dBnHL	66	95	90
Detectability of wave V at 50 dBnHL	8	31	28
G2-Sf			
Detectability of wave V at 90 dBnHL	82.5	100	100
Detectability of wave V at 80 dBnHL	65	100	97.5
Detectability of wave V at 70 dBnHL	5	41.5	39
Detectability of wave V at 60 dBnHL	0	0	0
G2-Ss			
Detectability of wave V at 90 dBnHL	100	100	100
Detectability of wave V at 80 dBnHL	70	100	95
Detectability of wave V at 70 dBnHL	0	85	80
Detectability of wave V at 60 dBnHL	0	65	55

RR, repetition rate.

Detectability of waves I and III

Waves I and III were analyzed at 90 dBnHL (Table 6). The percentage of detectability for those waves tended to decrease with the CE-chirp than click stimuli. The finding agrees with Rodrigues and Lewis [10]. They reported that detection of early waves achieved better with click stimulation when tested at (80, 60, 40, and 20 dBnHL) than with chirp stimuli.

On the other hand, Cebulla *et al*. [12] get to the conclusion that chirp stimulus was superior to the click regarding wave III detection. They reported that wave III was clearly identifiable in all chirp-evoked ABR at 60 dBnHL (100%) and at 40 dBnHL (98%). On the other hand, in click-evoked ABR, wave III could only be detected in 92% of the 60 dBnHL responses and 74% of the 40 dBnHL responses. They reported in the same study that wave I analysis showed a significant detectability reduction at both intensity levels using the chirp stimulus.

Correlation between pure-tone audiometry and each of chirp and click auditory brainstem response thresholds

Correlation between CE-chirp, click stimuli, and pure-tone audiometry

ABR threshold was determined as the lowest intensity at which significant repeatable response was detected (Table 7). In the current study, there was a high degree of correlation between CE-chirp, click, and behavioral PTA in all tested groups. The only reduced correlation between behavioral PTA and click stimuli was obtained in G2-Ss with severe steeping SNHL. In the current study, the correlation between both objective stimuli and behavioral threshold was consistent with that obtained by Maloff and Hood [8]. They found that ABR thresholds to chirps were closer to overall behavioral thresholds and this continues to occur in severe SNHL for chirp but not for click. The strongest correlations were observed between click-evoked ABR thresholds and pure-tone thresholds at 2 and 4 kHz [18].

Table 6: Detectability of waveforms I and III at 90 dBnHL in all tested groups

G1	Click (%)	Chirp 44 RR (%)	Chirp 35 RR (%)
Detectability of wave I	96	55	50
Detectability of wave III	100	78	73
G2-M			
Detectability of wave I	73	65	43
Detectability of wave III	88	73	58
G2-Sf			
Detectability of wave I	57.5	30	25
Detectability of wave III	67.5	60	35
G2-Ss			
Detectability of wave I	60	65	55
Detectability of wave III	60	75	65

RR, repetition rate.

On the other hand, reduced correlation between click and behavioral PTA in severe steeping SNHL (G2-Ss) could be explained on the basis of mode of cochlear excitation by click stimuli. In persons with impairment of auditory sensitivity in the higher frequency region, ABR generation may not necessarily follow this pattern with chirp stimuli [19].

In contrast to the above studies, Stapells *et al*. [20] have reported less agreement between click-evoked responses and behavioral thresholds at the same frequencies. They concluded that the result has been attributed to the click's broad spectrum. In their circumstance, the click-evoked threshold was related to the frequency (ies) for which hearing is best.

Correlation between NB-chirp and pure-tone audiometry

In the current study, there was a higher degree of correlation between NB-chirp ABR and behavioral PTA at the corresponding frequency in all tested groups, except in the G2-Sf subgroup at 500 Hz. This finding agrees with Xu *et al*. [21], who reported that there was a high degree of correlation between chirp ABR thresholds in both low-frequency and high-frequency audiometric bands in young patients with severe hearing loss. They concluded that increased sensitivity of the chirp ABR to

Table 7: Correlation between threshold of wave V (dBnHL) on using CE-chirp 44 repetition rate versus average of pure-tone audiometry threshold through a frequency range of 250 Hz and 8 KHz of all tested patients: correlation between threshold of wave V in dBnHL on using click stimuli with average pure-tone audiometry through a frequency range of 2000 and 4000 Hz of all tested patients

	CE-chirp 44 RR at frequency 0.5-4 K Hz	Click ABR at freq. 2-4 kHz	NB-chirp therapy at 500 Hz	NB-chirp therapy at 1000 Hz	NB-chirp therapy at 4000 Hz
G1	PTA at frequency 0.5-4 kHz	PTA at frequency 2-4 kHz	PTA at 500 Hz	PTA at 1000 Hz	PTA at 4000 Hz
r	0.666	0.681	0.877	0.581	0.751
P value	0.000	0.000	0.000	0.000	0.000
G2-M					
r	0.837	0.692	0.779	0.247	0.703
P value	0.000	0.000	0.000	0.021*	0.000
G2-Sf					
r	0.784	0.778	0.269	0.434	0.840
P value	0.000	0.000	0.112	0.001	0.000
G2-Ss	CE-chirp 44 RR at frequency0.5-4 kHz	Click ABR at frequency 2-4 kHz	NB-chirp at 500 Hz	NB-chirp at 1000 Hz	NB-chirp at 4000 Hz
	PTA at frequency 0.5-4 kHz	PTA at frequency 2-4 kHz	PTA at 500 Hz	PTA at 1000 Hz	PTA at 4000 Hz
r	0.858	0.425	0.631	0.553	0.808
P value	0.000	0.100	0.003	0.011*	0.000

ABR, auditory brainstem response; PTA, pure-tone audiometry; RR, repetition rate.It showed a correlation between threshold of wave V (dBnHL) by using NB-chirp 44 RR at 500, 1000, and 4000 Hz versus threshold of PTA at 500, 1000, and 4000 Hz of all tested patient.

more severe degrees of hearing loss may be attributed to the recruitment associated with cochlear hearing impairment [21].

The reduced correlation between NB-chirp and behavioral PTA in severe flat SNHL (G2-Sf) at 500 Hz agrees with Elberling and Don [9]. They reported that in objective frequency-specific assessment of hearing threshold using auditory-evoked potentials, there are greater differences at 500 Hz between the objective and the subjective threshold. This applies to simple tone burst ABR, to notched-noise ABR, and to the threshold assessed by means of ASSR. On the other hand, in severe steeping SNHL (G2-Ss) our results showed a high correlation between NB-chirp and behavioral PTA at 500 Hz. This could be attributed to the better synchronized activity in the better hearing low-frequency region that contributes to the frequency-specific chirp response < Pls check whether the change to region is fine>.

Conclusion

CE-chirp stimuli considered as a more effective recording method in threshold estimation in normal hearing and in sensory neural hearing loss with reduced time test and large amplitude of wave V than in C-ABR. Click stimulus was better than the CE-chirp stimulus at high-intensity levels regarding identification of waves I and III. Thus click-evoked ABR is still considered a better indicator of brainstem transmission time.

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Conflicts of interest

There are no conflicts of interest.

References

1. ANSI working group S3: 76 (published May 1.st 1998): Performance Measures of Micro-processor or Computer Controlled Pure-Tone Audiometers. Available at: www. dhsc.com. [Last accessed on 2016 Jun].
2. Weber B. The ABR Handbook: Auditory Brainstem Response. Ear and Hearing 1988;9:222.
3. Cebulla M, Sturzebecher E, Elbering C, Muller J. New clicklike stimuli for hearing testing. J Am Acad Audiol 2007; 18:725–738.
4. Dau T, Wagner O, Mellert V, Kollmeier B. Auditory brainstem responses with optimized chirp signals compensating basilar membrane dispersion. J Acoust Soc Am 2000; 107:1530–1540.
5. Elberling C, Don M, Cebulla M, Stürzebecher E. Auditory steady-state responses to chirp stimuli based on cochlear traveling wave delay. J Acoust Soc Am 2007; 122:2772–2785.
6. Elberling C, Don M, Callo J. Evaluation auditory brainstem responses to different chirp stimuli at three levels of stimulation. Acoust Soc Am 2010; 128:215–232.
7. Kristensen S, Elberling C. Auditory brainstem responses to level-specific chirps in normal-hearing adults. J Am Acad Audiol 2012; 23:712–721.
8. Maloff E, Hood L. A comparison of auditory brain stem responses elicited by click and chirp stimuli in adults with normal hearing and sensory hearing loss. Ear Hear 2014; 35:271–282.
9. 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; 124:3022–3037.
10. Rodrigues G, Lewis D. Comparison of click and CE-chirp® stimuli on brainstem auditory evoked potential recording. Rev Soc Bras Fonoaudiol 2012; 17:412-416.
11. Dau T, Wegner O, Mellert V, Kollmeier B. Auditory brainstem responses with optimized chirp signals compensating basilar-membrane dispersion. The Journal of the Acoustical Society of America 2000;107:1530-40.
12. Cebulla M, Lurz H, Shehata-Dieler W. Evaluation of waveform, latency and amplitude values of chirp ABR in newborns. Int J Pediatr Otorhinolarynol 2014; 78:631–336.
13. Sininger YS, Cone-Wesson B, Folsom RC, Gorga MP, Vohr BR, Widen JE, Ekelid M, Norton SJ. Identification of neonatal hearing impairment: auditory brainstem responses in the perinatal period. Ear Hear 2000; 21:383–399.
14. Hall III JW. Application of ABR in objective assessment of infant hearing. Audiology Online [internet]. 2013.
15. Elberling C, Kristensen S, Don M. Auditory brainstem responses to chirps delivered by different insert earphones. J Acoust Soc Am 2012; 131:2091–2100.
16. Musiek F, Baran J. The auditory system; physiology, and clinical correlates. Cochlear Physiol 2007; 5:97–111.
17. Vander Werff K, Brown C, Gienapp B, Schmidt C, Kelly M. Comparison of auditory steady-state response and auditory brainstem response thresholds in children. J Am Acad Audiol 2002; 13:227–235.
18. van der Drift J, Brocaar M, van Zanten G. The relation between the pure-tone audiogram and the click auditory brainstem response threshold in cochlear hearing loss. Audiology 1987; 26:1–10.
19. Hall J. *New handbook of auditory evoked responses* ISBN 0-205-36104-8. OCLC. 71369649]. Boston, MA: Pearson; 2007.
20. Stapells D, Picton T, Durieux-Smith A. Electrophysiological measures of frequencies specific auditory function. In: Jacobson JT ed. *Principles and applications in auditory evoked potentials*. Needham Heights, MA: Allyn and Bacon; 1994. 251–283.
21. Xu Z, Cheng W, Yao Z. Prediction of frequency-specific hearing threshold using chirp auditory brainstem response in infants with hearing losses. Inter J Ped Otolaryng 2014; 78:812–816.