Comparison of chirp and click-evoked brainstem response stimulus in children with moderate and severe sensorineural hearing loss

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Introduction
Auditory brainstem response using click stimuli enable global objective estimation of hearing threshold. Recently, it has been suggested that a chirp stimulus may produce a synchronous response from a large portion of basilar membrane. The chirp was designed to produce simultaneous displacement maxima along the cochlear partition by compensating for frequency-dependent traveling-time differences.

Material and methods
In this study, response characteristic of both click and chirp stimuli are compared in children. We compared latency and amplitude of wave V at different intensity levels and waves I and III at high level.

Results and conclusion
Results show that wave V on using chirp stimuli could be detected easier with shorted in latency and larger in amplitude than in click auditory brainstem response. However, click stimulus was better than chirp stimulus at high-intensity levels with respect to the identification of waves I and III.

Keywords:
brain stem response, children, chrips, click evoked, sensorineural hearing loss

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Introduction

Auditory brainstem response (ABR) is the most popular and precise method for hearing impairment detection [1,2]. Click ABR is abrupt and rapid onset, have broad spectrum non frequency specific response. ABR needs good neural synchrony; the greater number of neurons that fire results in a larger response amplitude Michael *et al.* [1]. In click ABR the cochlear traveling wave takes some time to reach from the base of the cochlea to its apical end. Therefore, the different neural unit activity 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]. In chirp stimulus, input compensation in auditory method uses a stimulus that 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 cochlear partition is delayed. Subsequently, 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 aimed to compare click and chirp ABR latencies and amplitude in normal-hearing children and children with both moderate and severe sensory neural hearing loss (SNHL).

Methods

In this study, a total number of 90 children with an age range of 6–12 years were included. The control group (G1) consisted of 30 participants with bilateral normal peripheral hearing. The study group consisted of 60 participants. They were divided into two subgroups: 30 participants with moderate SNHL (G2-M) and 30 participants with severe SNHL (G2-S). This subgroup (G2-S) was divided into two subgroups: 20 participants with flat audiometric (G2-Sf) configuration pattern and 10 participants with steeping audiometric configuration pattern (G2-Ss). All children were tested in a sound-treated room model no. RE. 24, acoustic immettancemeter model Interacoustics AZ26 with a probe tone of 220 Hz, pure-tone audiometer Interacoustics model AC40 with headphones TDH39, and bone vibrator B71 and auditory evoked potentials model Interacoustics Eclips25 (Arlington Heights, Illinois, USA). All of them were subjected to careful history taking, full audiological history, basic audiological evaluation including pure-tone

audiometry 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.

Statistical analysis

Simple descriptive statistics were performed to calculate numerical parametric data as mean, SD, and minimum and maximum of range, whereas categorical data were presented as number and percentage. Inferential analyses were performed for quantitative variables using the paired *Z*-test in case of two independent groups with parametric data. The level of significance was taken at *P* value less than 0.05, which was considered significant, and *P* value less than 0.01 was considered highly significant, otherwise as nonsignificant.

Results

Results of the study are as follows: comparison of wave I, III, and V latencies and amplitudes between click ABR and chirp stimuli [44 repetition rate (RR)] of all tested groups (Figs 1–3) and (Tables 1–4).

Discussion

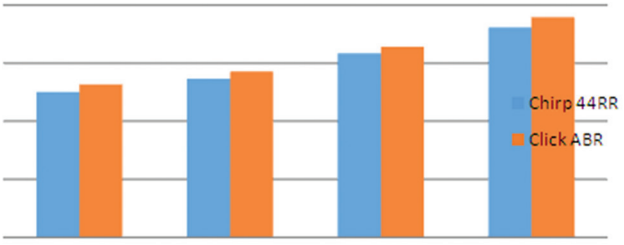
Wave latency

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 decreased. 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 is in agreement with the findings of [7,8]. They reported that the chirps give shorter detection time and higher signal-to-noise ratio compared with the click. The results indicate that a chirp is a more efficient stimulus compared with a click for the recording of auditory evoked responses in normal-hearing individuals using transient sounds. In addition, this finding is in agreement with the findings of Elberling and Don [9], who reported that the latencies obtained with the CE-chirp stimulus are shorter than those obtained with clicks. 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. However, this finding is in disagreement with the findings of Rodrigues and Lewis [10]. They reported that click latencies were shorter than those obtained with CE-chirp stimulus at 80, 60, 40, and 20 dBnHL.

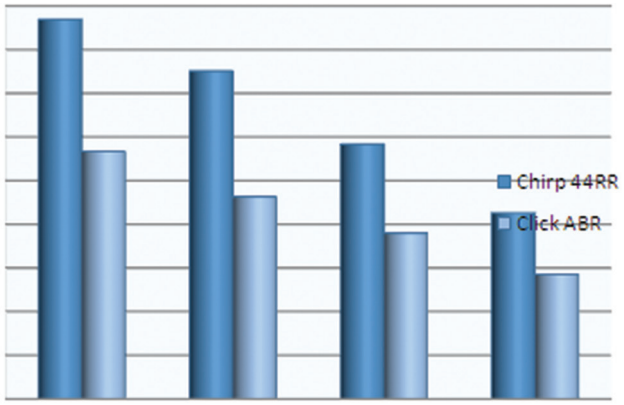
Study subgroup G2-M showed a highly statistically significant shorter wave V latencies provoked by

Figure 1



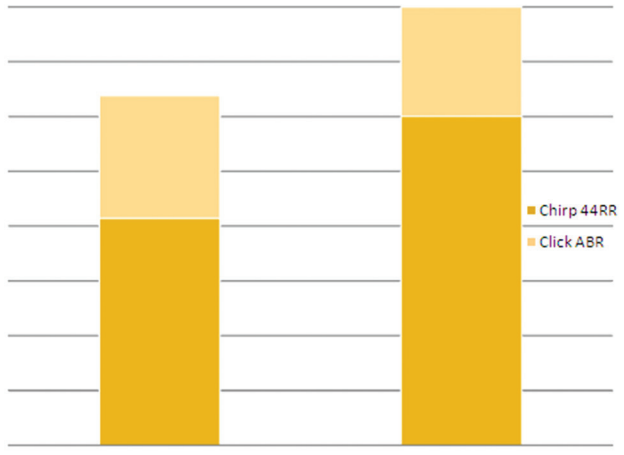
The difference in wave V latency (in ms) at four intensity levels in G1 group on comparing between chirp stimuli using 44RR versus click ABR. ABR, auditory brainstem response; RR, repetition rate.

Figure 2



The difference in wave V amplitude (in μv) at four intensity levels (90, 70, 50, and 30 dBnHL) in G1 group on comparing between chirp 44RR versus click ABR. ABR, auditory brainstem response; RR, repetition rate.

Figure 3



The difference in wave I and III amplitude (in μv) in G1 group at 90 dBnHL on comparing between chirp 44RR versus click ABR. ABR, auditory brainstem response; RR, repetition rate.

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

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

**Significance of <0.05; ABR, auditory brainstem response; RR, repetition rate.

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

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

**Significance of <0.05; ABR, auditory brainstem response; RR, repetition rate.

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

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

**Significance of <0.05; ABR, auditory brainstem response; RR, repetition rate.

Table 4 The comparison of wave I and III amplitudes (in μv) at 90 dBnHL between chirp 44 repetition rate versus click auditory brainstem response in all tested groups

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

*Statistically significant, **Significance of <0.05; ABR, auditory brainstem response; RR, repetition rate.

CE-chirp compared with click stimuli at 90, 70, and 60 dBnHL levels. However, 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 ABR thresholds to chirps were closer to behavioral thresholds and better than clicks in ears with moderate SNHL [8].

Study subgroup G2-Sf showed that CE-chirp stimuli presented wave V latencies significantly shorter than those observed with clicks only at intensity level 90 dBnHL. However, at 80 dBnHL, wave V presented with no statistically significant difference in latencies between CE-chirp and click stimuli. However, at 60 and 70 dBnHL there were no valid cases of wave V

on using click ABR stimulus to perform a comparison with CE-chirp. This finding is in agreement with the findings of Torsten and colleagues [8,11], who demonstrated that, at the highest levels of stimulation with chirp, the early low-frequency energy of the chirp probably stimulates the basal regions of the BM due to an upward spread of excitation and produces synchronous discharges of VIIIth-nerve fibers along the length of the human cochlear partitions. Otherwise, neural response to chirps at lower intensity levels is likely dominated by lower frequency cochlear regions, which are characterized by longer latencies.

In the study subgroup G2-Ss, the CE-chirp stimuli showed wave V latencies shorter than those observed with clicks only at intensity level 90 dBnHL. However, at 80 dBnHL, there was no statistically significant difference in wave v latencies between CE-chirp and click stimuli. In addition, at 70 and 60 dBnHL, CE-chirp could not be compared with click as there were no valid cases of wave V on using click ABR. This could be attributed to the fact that neural remnants were better at apical areas of the cochlea. This indicates the ability of the chirp stimuli to get use of the neural charges of the apical areas allowing better production of the waveforms. This is in agreement with the findings of Maloff and Hood [8] and Elberling *et al.* [6].

Latencies of waves I and III

In all groups of the current study, regardless of the stimulus type, wave I and III latencies were analyzed at high-intensity levels (90 dBnHL). Group G1 showed no statistically significant differences between click and chirp stimuli as regards wave I and III latencies. These findings are in agreement with the findings of Torsten *et al.* [11], who reported that, at the highest stimulation level, the typical early peaks are similar nearly in their responses to the click as well as to the broad band chirp. In the same study they reported that 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, whereas the generator for wave V probably has a flatter frequency response.

The subgroup G2-M showed no statistically significant differences between click and CE-chirp stimuli as regards wave I latency at 90 dBnHL level. These findings are in agreement with the findings of Torsten *et al.* [11]. However, there was a highly statistically significantly shorter latency as regards wave III on using CE-chirp compared with click stimuli. This may be attributed to the fact that hearing loss had its effect on the generator of waves I and it causes latency shift of wave I on using CE-chirp stimuli. These findings are in agreement with the findings of Cebulla *et al.* [12].

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

Accordingly, the ability to detect early waves helps in diagnosing the type of hearing loss by allowing the calculation of waves I–III, III–V, and I–V interpeak latency, which are useful to determine conductive hearing loss or central causes of hearing loss [13].

Wave amplitude

Wave V amplitude

In the current study, 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). This finding is in agreement with that of Cebulla *et al.* [12], who reported significantly higher amplitudes of wave V responses on using chirp-evoked ABR compared with 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. The results of this research work are in agreement with our research results).

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 threshold.

However, the results of the current study did not agree with those of Rodrigues and Lewis [10], who demonstrated a smaller wave amplitude 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 compared with the traditional stimulus [14]. This is contrary to the current research outcome. Our results indicate that at high-intensity levels, chirp produced better amplitude outcome.

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. However, at 60 dBnHL, there were no significant differences in amplitude between the two stimuli. However, at 50 dBnHL, CE-chirp could not be compared with click as there were no valid cases of wave V on using click ABR outcome. This is in agreement with the findings of [8,12], who explained that increased temporal synchrony of a chirp generates better waveform at high-intensity levels. However, the results of the current study disagree with those of 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 study subgroups G2-Sf and G2-Ss continued to show that the amplitudes of wave V obtained with the CE-chirp stimulus were significantly larger than those obtained with clicks at 90 and 80 dBnHL in subgroup G2-Sf. This finding is in agreement with that of [8,12]. However, the study subgroup G2-Ss at 80 dBnHL 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 difference in threshold detectability that was more favorable in chirp compared with click. In other words, wave V was close to behavior threshold of PTA on using CE-chirp compared with click 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 amplitudes

In all groups of the current study, regardless of the stimulus type, wave I and III amplitudes were analyzed at 90 dBnHL. 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 that of Elberling *et al.* [15]. They stated that, to improve the chirp stimulus design, waves I and III could be absent. Accordingly, wave I and III amplitudes were smaller than those for the corresponding click stimuli ABR at the same intensity level.

The amplitude analysis of waves I and III in subgroups 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 is in agreement with that of 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.

Conclusion

CE-chirp stimuli considered as a more effective recording method in threshold estimation in normal hearing and in SNHL with reduced time test and a large amplitude of wave V than in click ABR. Click stimulus was better compared with CE-chirp stimulus at high-intensity levels as regards 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.

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