Auditory brainstem response to chirp stimulus in children with moderate and severe sensorineural hearing loss

Amal M. El-Attar[a], Sayed M. Enass[a], Mossa M. Hoda Abu[b], Mahran M. Sanaa[b]

[a]Audiology Unit, Department of ENT, Faculty of Medicine, Assiut University, Assiut, [b]Department of Otolaryngology, Assiut University, Hearing and Speech Institute, Cairo, Egypt

Correspondence to Mahran M. Sanaa, M.Sc, Hearing and Speech Institute, Cairo, Egypt
Tel: +20 101 484 3535;
e-mail: entsana2@gmail.com

Received 14 August 2016
Accepted 09 October 2016

Journal of Current Medical Research and Practice
May-August 2017, 2:136–140

Introduction
Click auditory brainstem response (ABR) is abrupt, has a rapid onset, and has a broad spectrum nonfrequency-specific response. ABR needs good neural synchrony, i.e., the greater number of neurons that fire results in a larger response amplitude. 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, we attempt to find a correlation between pure tone threshold (PTA) and each of the click and chirp ABR thresholds in children with moderate and severe sensory neural hearing loss (SNHL).

Results and conclusions
Results show that there is a significant correlation between chirp and behavioral PTA and between click and behavioral PTA in children with normal hearing and hearing impaired but not in those with severe steeping SNHL. In steeping SNHL, there was reduced correlation between behavioral PTA and click ABR stimuli. In addition, there was a significant correlation between narrow band-chirp at 500, 1000 Hz, and 4000 Hz and behavioral PTA in children with normal hearing loss and SNHL but not in those with severe steeping SNHL. In this category, there was a reduction in correlation between behavioral PTA and narrow band-chirp ABR stimuli.

Keywords:
brain stem response, children, chrisp, sensorineural hearing loss

J Curr Med Res Pract 2:136–140

2357-0121

Introduction

Objective test such as the auditory brainstem response (ABR), is one of auditory-evoked potentials. It enables the examiner to obtain a threshold audiogram and to assess the status of peripheral auditory function without requiring participation from the patient being evaluated [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 units' activity along the cochlear partition will not be stimulated at the same time and the neural activity across all nerve fibers will be smeared [2-4]. In an attempt to compensate for the dispersion in the human cochlea, a chirp has previously been designed from the cochlear delay based on derived band ABR latencies. It depends on the cochlear filter build-up time and on the unit response waveform; it means that the lack of the temporal synchrony can be partly neutralized by an upward chirp stimulus [4].

In this study, Claus Elberling Chrisp (CE-chirp) has been used; the CE-chirp has been refined over the years by Claus Elberling, the man who the CE-chirp has been named in honor of. This chirp differs from many previous implementations in that the amplitude spectrum is designed to be within five octave bandwidth from 350 to 11,300 Hz. There are also four narrow band (NB) CE-chirps having center frequencies at 500, 1000, 2000, and 4000 Hz. The broadband chirp can be constructed by summing the NB stimuli [5].

Methodology

In this study, 90 children with age range from 6 to 12 years were included. The control group (G1) consisted of 30 individuals with bilateral normal peripheral hearing. The study group consisted of 60 individuals, and they divided into2 subgroups: 30 individuals with moderate sensorineural hearing loss (SNHL) (G2-M) and 30 individuals with severe SNHL (G2-S). This subgroup (G2-S) was further divided into two subgroups: 20 individuals with flat

audiometric (G2-Sf) configuration pattern and 10 individuals with steeping audiometric configuration pattern (G2-Ss). All children were tested in a sound-treated room (model no. RE 24), with a acoustic immittancemeter model (Interacoustics AZ26 (Middelfart, Denmark)) with a probe tone 220 Hz, using a pure tone audiometer (Interacoustics model AC40 (Middelfart, Denmark)) with headphones TDH39 and bone vibrator B71 and auditory-evoked potentials model Interacoustics Eclipse 25 (Middelfart, Denmark). All of them were subjected to careful history taking; full audiological history; basic audiological evaluation, including a pure tone audiometry for both air conduction (for the frequency range 250–8000 Hz) and bone conduction (for the frequency range 500–4000 Hz); and 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 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 *P* less than 0.05, was considered significant, and *P* less than 0.01 is considered highly significant, otherwise it is nonsignificant for continuous variables. Pearson's correlation test was used to compare correlation between different continuous variables. *P* less than 0.05 was considered significant, and *P* less than 0.01 is highly significant, otherwise it is nonsignificant.

Results

Results of the study are given below.

Comparison of waves I, III, and V latency and amplitude between click ABR and chirp stimuli [44 repetition rate (RR)] of all tested groups.

Data in Table 1 shows that detectability of wave V near threshold was more on using CE-chirp than click stimuli.

Data is Table 2 shows that detectability of waves I and III was more on using click stimuli than chirp stimuli.

Table 3 shows that there were correlations found between subjective and objective stimuli. Both chirp and click stimuli were highly correlated with pure tone averages. In subcategory G2-Sf, no correlation was found between subjective and objective stimuli at 500 Hz with NB-chirp, whereas in subcategory G2-Ss, no correlation was found between subjective and objective stimuli using click and NB-chirp at 1000 Hz.

Discussion

Waveform detectability in all study groups

Detectability of wave V

In the current study, wave V was (100%) detectable at all tested ears in normal group (G1). This occurred when the presence/absence of wave V was analyzed at 90, 70, 50, and 30 dBnHL on using either CE-chirp or click. In all study groups (G2-M and G2-S), wave

Table 1 The detectability of wave V in all tested groups

	Click (%)	Chirp 44RR (%)	Chirp 35RR (%)
G1			
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.

Table 2 The detectability of waveforms I and III in all tested groups

	Click (%)	Chirp 44RR (%)	Chirp 35RR (%)
G1			
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.

Table 3 Correlation between threshold of wave V in dBnHL on using CE-chirp 44RR versus average of pure tone audiomertry threshold through frequency range 250 and 8 KHz of all tested individuals

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

Correlation between threshold of wave V in dBnHL on using Click stimuli with average PTA through frequency range 2000 and 4000 Hz of all tested individuals. Also it showed correlation between threshold of wave V in dBnHL by using NB-chirp 44RR at 500, 1000, and 4000 Hz, versus threshold of PTA at 500, 1000, and 4000 Hz of all tested individuals. ABR, auditory brainstem response; NB, narrow band; PTA, pure tone threshold.

V was detectable in all tested ears at high levels. When intensity levels were reduced till obtaining threshold, wave V detectability was better when using CE-chirp stimulation than with click stimuli. The finding of the present study agrees with Cebulla *et al.* [6]. They demonstrated that wave V was always identifiable when using 60 dBnHL stimulus level (100%). At 40 dBnHL (near-threshold level), wave V was reliably recognizable in 95% of the click-evoked ABR and in 100% of the chirp-evoked ABR in neonates who passed hearing screening. Those findings were reported when they compared ABR with chirp and click stimuli at two intensity levels 60 and 40 dBnHL (Table 1).

The subgroup G2-Sf showed detectable wave V in 82.5% when using click stimuli. This percentage improved to 100% on using chirp stimuli at the same 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 44RR and 39% with chirp 35RR, and only 5% with click), whereas there was no identifiable wave V at 60 dBHL for all stimuli. This result emphasized the absence of ABR waves at high-intensity levels, with click not necessarily implying total deafness. It is well known that click ABR threshold represent hearing in the 2–4 kHz and is dependent on the mean threshold of both latencies. Our speculation may be that CE-chirp by its ability for synchronized firing can get use to fewer remaining neurons in producing ABR response than the click. This speculation agrees with Maloff and Hood [7] who obtained detectable wave V close to behavior threshold of pure tone threshold (PTA) on using CE-chirp than click stimuli and referred that to increased temporal synchrony. This indicates that chirp generates significantly larger compound neural responses than click.

Detectability of waves I and III

Waves I and III were analyzed at 90 dBnHL. The percentage of detectability for those waves tended

to decrease with the CE-chirp than click stimuli. It is worth mentioning that obtaining waves I and III and subsequently calculating I–III and I–V interpeak latencies have great diagnostic value in ABR recording. In the current research work, we could detect the early waves I and III with different percentage in all groups. The finding of our study agrees with Rodrigues and Lewis [8]. 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. They demonstrated that earlier latencies encountered by chirp stimulus may lead to harder visualization of early waves that became compressed in a small window frame (Table 2).

On the contrary, Cebulla *et al.* [6] got to the conclusion that chirp stimulus was superior to 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%). However, 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. The discrepancy of the results between the current study and their study referred to difference in methodology and subject characteristics, which accounted for the reported variability in percent detectability of ABR early waves.

In contrast to both of our results and previous results, Torsten *et al.* [9] demonstrated that the responses evoked by the chirp did not show clear earlier peaks I and III. They considered this was owing to cancellation of overlapping responses at high stimulation levels. At those levels, the early low-frequency energy in the chirp stimulates basal regions of the basilar membrane owing to upward spread of excitation. In addition, they reported that the discrepancy in the behavior of wave V with respect to the earlier waves suggests some sort of neural reorganization at the level where wave V is generated.

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

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

ABR threshold was determined as the lowest intensity at which significant repeatable response was detected. 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 subgroup (G2-Ss) with severe steeping SNHL. In the current study, the correlation between both objective stimuli and behavioral threshold was consistence with that obtained by Maloff and Hood [7]. They found that ABR thresholds to chirps were closer to overall behavioral thresholds, and this continue to occur in severe SNHL for chirp but not for click. The strongest correlations were observed between click-evoked ABR thresholds and PTAs at 2 and 4 kHz [10-12] (Table 3).

On the contrary, reduced correlation between click and behavioral PTA in severe steeping SNHL (G2-Ss) could be explained based on mode of cochlear excitation of the cochlea by click stimuli. An ABR evoked by moderately intense click signals reflects activation of the high-frequency region of the cochlea, with no contribution from low frequency in click ABR, especially in normal hearing subjects. In persons with impairment of auditory sensitivity in the higher frequency region, ABR generation may not necessarily follow this pattern with chirp stimuli [13]. Moreover, Hall [14] reported that a high-frequency steeping loss that begins around 2000 Hz and slopes steeply might result in the presence of an ABR with delayed latency.

In contrast to the aforementioned studies, Stapells *et al.* [15] 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.

From a clinical point of view, chirp stimulus was superior to the click stimulus in evoking lower thresholds ABR. Accordingly, it is advisable to use chirp-evoked ABR for the clinical estimation of hearing thresholds rather than click-evoked ABR specially in severe SNHL [16]. In the current study, we obtained a better waveform quality which was less influenced by residual electroencephalogram with chirp stimuli. This finding added to the better correlation with behavioral threshold, making chirp stimuli more advisable for clinical use. This finding agrees with Mühler *et al.* [17] who concluded that reduced residual electroencephalogram noise level with chirp stimuli and increased response amplitude may contribute to a more reliable estimate of the hearing threshold and to a more accurate labeling of peak latency.

Correlation between narrow band-chirp and pure tone threshold

The goal for obtaining information about low-frequency, mid-frequency, and high-frequency

range is to give a clue about actual audiometric configuration and to provide a complete assessment of hearing sensitivity [17]. 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 G2-Sf subgroup at 500 Hz. This finding agrees with Xu *et al*. [18] who reported there was a high degree of correlation between chirp ABR thresholds in both low- and high-frequency audiometric bands in young patient with severe hearing loss. They concluded that increased sensitivity of the chirp ABR to more severe degrees of hearing loss may be attributed to the recruitment associated with cochlear hearing impairment [18].

The reduced correlation between NB-chirp and behavioral PTA in severe flat SNHL (G2-Sf) at 500 Hz agrees with Elberling and Don [19]. 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 thresholds. This applies to simple tone burst ABR, to notched-noise ABR, and to the threshold assessed by means of auditory steady-state response. They speculated that this is mainly because of the poor synchronization between the excitation of individual nerve fibers. Moreover, it may be a consequence of the lower speed of traveling wave in this low-frequency region of the cochlea compared with the basal region. On the contrary, 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 rejoin that contribute to the frequency-specific chirp response.

This study demonstrated that CE-chirp stimuli evoke clearly higher ABR wave V amplitudes with shorter latencies than standard clicks. This may lead to significantly reduced testing time in either normal hearing subjects or those with SNHL. In addition, CE-chirp and NB-chirp showed better correlation with behavioral thresholds. This gives a clue about actual audiometric configuration in children. This is necessary in the process of quantification of the degree of hearing impairment for better management plans.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

References

1 Lins G, Picton T, Boucher B, Durieux-Smith A, Champagne G, Moran M, *et al*. Frequency-specific audiometry using steady-state responses. Ear Hear 1996; 17:81–96.

2 Cebulla M, Sturzebecher E, Elbering C, Muller J. New clicklike stimuli for hearing testing. J Am Acad Audiol 2007; 18:725–738.

3 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.

4 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.

5 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.

6 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.

7 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.

8 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.

9 Torsten D, Oliver W, Volker M, Birger K. *Auditory brainstem responses with optimized chirp signals compensating basilar-membrane dispersion*. Oldenburg, Germany; Carl von Ossietzky Universita¨t Oldenburg, AG Medizinische Physik; D-26111; 1999.

10 Gorga M, Worthington D, Reiland J, Beauchaine K, Goldgar D. Some comparisons between auditory brainstem response thresholds, latencies and the pure-tone audiogram. Ear Hear 1985; 6:105–112.

11 Jerger J, Mauldin L. Prediction of sensorineural hearing level from the brainstem evoked response. Arch Otolaryng 1978; 104:456–461.

12 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.

13 Hall J. *New handbook of auditory evoked responses*. Boston: Pearson; 2007.

14 Hall J. Applicationof ABR in objective assessment of infant hearing. Plural publishing, San Diego, CA, USA. Audiology Online 2013; 12079. Available at: *http://www.audiologyonline.com*. [Last accessed on 2016 Jul 11].

15 Stapells D, Picton T, Durieux-Smith A. Electrophysiological measures of frequencies specific auditory function. In: Jacobson JT, editor. *Principles and applications in auditory evoked potentials*. Needham Heights, MA: Allyn and Bacon; 1994. 251–283.

16 Sininger Y, Folsom R, Gorga M, Vohr B, *et al.* Identification of neonatal hearing impairment: auditory brainstem responses in the perinatal period. Ear Hear 2000; 21:383–399.

17 Mühler R, Rahne T, Verhey J. Auditory brainstem responses to broad-band chirps: amplitude growth functions in sedated and anaesthetized infants. Int J Pediatr Otorhinolaryngol 2013; 77:49–53.

18 Xu Z, Cheng W, Yao Z. Prediction of frequency-specific hearing threshold using chirp auditory brainstem response in infants with hearing losses. Inter J Pediatr Otorhinolaryngol 2014; 78:812–816.

19 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.