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Relationship between pure tone audiometry and tone burst auditory brainstem response at low frequencies gated with Blackman window

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Abstract

To assess the reliability of Blackman windowed tone burst auditory brainstem response (ABR) as a predictor of hearing threshold at low frequencies. Fifty-six subjects were divided in to three groups (normal hearing, conductive hearing loss, sensorineural hearing loss) after pure tone audiometry (PTA) testing. Then they underwent tone burst ABR using Blackman windowed stimuli at 0.5 kHz and 1 kHz. Results were compared with PTA threshold. Mean threshold differences between PTA and ABR ranged between 11 dB at 0.5 kHz and 14 dB at 1 kHz. ABR threshold was worse than PTA in each but 2 cases. Mean discrepancy between the two thresholds was about 20 dB in normal hearing, reducing in presence of hearing loss, without any differences in conductive and sensorineural cases. Tone burst ABR is a good predictor of hearing threshold at low frequencies, in case of suspected hearing loss. Further studies are recommended to evaluate an ipsilateral masking such as notched noise to ensure greater frequency specificity.

Keywords: ABR Tone bursts Blackman window Hearing threshold

Introduction

With the increasingly widespread implementation of universal newborn hearing screening programs, objective audiometric techniques must be more accurate in order to assess hearing levels in young infants at an early stage. Two main techniques have been used for this purpose: the auditory steady state evoked response (ASSR) [*1*] and the tone burst auditory brainstem response (ABR) [*2*].

Unfortunately, both techniques are not universally available and their results are still not reliable predictors of the hearing thresholds. In fact, although the auditory brainstem responses (ABR) evoked by clicks are the most frequently used in clinical practice, from their early introduction on, it was clearly realized that they could not provide frequency-specific information because of their spectral splatter (i.e. sidebands of energy above and below the nominal frequency of the stimulus) [*3*]. In fact, ABR testing records simultaneous responses from a large number of neural units that are best elicited by a stimulus characterized by an abrupt or rapid onset and a broad frequency bandwidth (i.e. click). Therefore this kind of test can only give information about hearing level in the range between 2000 and 4000 Hz, frequencies which are represented in the most basal portion of the cochlea [*4*].

ASSRs evoked by modulated tones might estimate the audiogram more precisely than tone ABRs, but there is a lack of normative and clinical data available in the literature if compared to tone-ABR [*5–8*]. ASSRs are the responses to single continuous tones modulated in amplitude (AMT) at rates ranging between 75 and 110 Hz. This response, is because of the synchronous discharge of auditory neurons in the brain stem, is periodic and phase locked to the modulation frequency of the carrier stimulus and consequently can be best represented in the frequency rather than time domain. Analyzing the response in the frequency domain, a single peak that represents the periodicity of the response comes out from EEG spectrum [*7*].

Perez-Abalo et al. [*7*] have obtained reliable estimates of behavioral pure-tone thresholds in adults with normal hearing, well babies, and hearing impaired subjects using ASSR to single AMT. Since sinusoidal modulated tones are not significantly distorted by free-field speakers and microphones, ASSR might also be used to evaluate the performance of hearing aids [*9*]. However data are still not yet homogeneous; in normal hearing subjects mean threshold difference between ASSR and behavioral audiometry is reported in the range of 11–18 dB, 10–30 dB and up to 34 dB in different papers [*7*, *8*].

The tone burst ABR (TB-ABR), with a 2 cycles rise time, 1 cycle plateau and 2 cycle fall time stimulus (2-1-2 tone bursts), is considered a reasonable compromise between the requirements of a short onset, in order to elicit a well defined ABR, and a long one, in order to minimize the spread of energy to frequencies adjacent to the nominal frequency of the tone burst [*3*, *10*].

There are only few papers about TB-ABR using Blackman window, which is a stimulus characterized by 1 ms rise and fall times and no plateau [*11*, *12*], implemented to reduce spectral splatter and increase frequency specificity of tone burst stimulation. The goal of these studies was finding a way to reduce the underestimation of high frequencies hearing loss; to do so they compared TB-ABR using Blackman window with TB-ABR with linearly gated stimuli, but no clear differences were found between them in terms of how precisely ABR thresholds predicted pure tone thresholds at 2000 and 4000 Hz. Blackman windowing has not been studied on ABR at low frequencies.

The aim of this study was to evaluate the possibility of predicting a hearing threshold, at low frequencies, since high frequencies are well studied by click ABR, using TB-ABR with Blackman window and its applicability in clinical practice.

Materials and methods

The study protocol was approved by the local Ethics Committee and informed consent was obtained by each subject. The study group consisted of 56 volunteers, aged 19–60 years (mean 47), 28 females (50%) and 28 males (50%).

Each subject was submitted to pure-tone audiometry (PTA) threshold detection in a sound proof chamber by the same examiner (EP) and with the same device (AMPLAID 309, AMPLIFON, ITALY) monthly calibrated. Frequencies tested ranged from 250 to 8000 Hz.

The study was conducted analyzing only right ear threshold. On the basis of right ear PTA threshold, 24 subjects (43%) were normally hearing (NH), i.e. PTA threshold better than 25 dB at each frequency tested, and 32 (57%) were affected by hearing loss. Among the 32 subjects affected by hearing loss 16 (50%) were affected by sensorineural hearing loss (SNHL), 16 (50%) by conductive hearing loss (CHL). Hearing-impaired subjects showed PTA thresholds at 0.5 and 1 kHz between 40 and 70 dB. None of the hearing-impaired patients was affected by mixed type hearing loss or retrocochlear diseases.

After PTA all subjects underwent TB-ABR recording using the EP 25 device (AMPLIFON, ITALY). Patients were tested awake, but relaxed while seated in a reclining chair in a quiet environment; electrodes were placed with electrolytic paste on high forehead and on both mastoids.

Stimuli consisted of 0.5 and 1 kHz tone bursts, gated on using Blackman window, through TDH 49 earphones at variable intensities until threshold values. Stimulation rate of 39.1 Hz, low- and high-pass filters set at 1,500 and 30 Hz, respectively, and averaging of 1,000 sweeps were used.

There are no standards for intensity calibration of the used stimuli. Because of their short duration the loudness of the stimuli is softer than with longer-duration tone bursts. In order to specify psychoacoustic intensity we measured the mean difference between the hearing thresholds assessed with the tone bursts used in the study and with pure tone longer stimuli (from 250 ms on) in a group

of 20 normal hearing subjects. The mean differences were 10 dB at 0.5 kHz and 5 dB at 1 kHz; these correction factors were subtracted to threshold values obtained by means of ABR (dB nHL) in order to compare PTA and ABR thresholds.
Each ABR recording was repeated twice at all intensities starting from 100 dB nHL; then stimuli intensity was progressively reduced by 5 dB steps until wave V disappeared. All ABRs tracings were evaluated by three examiners (ML, AC, RA) and threshold was defined only if all of them agreed on the identification of wave V.
The statistical evaluation of data was carried out by means of SPSS software and a p level of 0.05 was considered to be the limit of significance.

Results

In Table 1 hearing thresholds obtained by means of PTA and ABR at 0.5 and 1 kHz and the differences between the two types of thresholds are reported.

Table 1
PTA and ABR mean thresholds and mean differences between the two tests in the whole group

	0.5 kHz	**1 kHz**
PTA	35 (26)	35 (26)
ABR	46 (21)	49 (22)
Difference	11 (9)	14 (8)

Standard deviation values in brackets

Mean threshold differences between PTA and ABR ranged between 11 dB at 0.5 and 14 dB at 1 kHz. ABR threshold was always worse than PTA threshold except for two cases, one at 0.5 and one at 1 kHz, in whom ABR threshold was 5 dB better than PTA.
The distribution of PTA-ABR threshold difference was normal and is shown in Fig. 1. Dispersion was higher at 0.5 kHz; mean difference between PTA and ABR threshold was larger at 1 kHz. In 66% of cases, threshold difference between the two tests ranged from 5 to 20 dB.

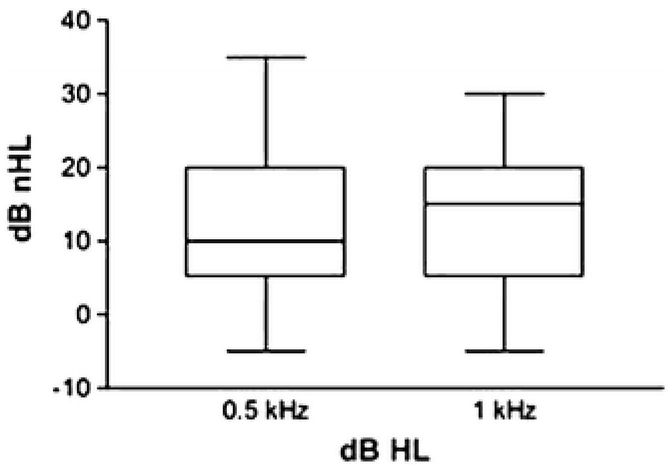

Fig. 1
Distribution of values referred to the difference between PTA and ABR threshold at 0.5 and 1 kHz

Mean latency values of the wave V at threshold level of stimulation was 9.44 ms (SD 1.60) at 0.5 kHz and 9.01 ms (SD 1.11) at 1 kHz.

PTA and ABR threshold correlation was significant at the Pearson's test at both frequencies tested ($r = 0.9$ at 0.5 and 1 kHz, $p < 0.001$). In Fig. 2 the relationship between PTA and ABR threshold is graphically reported by means of the linear regression analysis. The slope of the linear regression was 0.8 with y intercept at 20 dB. The pattern of the regression shows that the discrepancy between the two thresholds is about 20 dB in normal hearing and becomes smaller in presence of hearing loss, as demonstrated by the slope of the linear regression, which is <1.

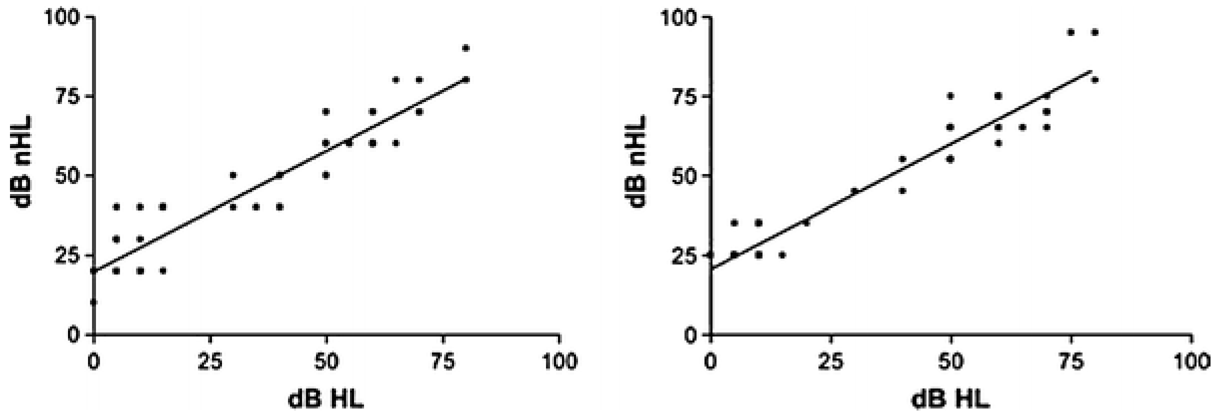

Fig. 2

Linear regression analysis of the relationships existing between PTA (x axis) and ABR thresholds (y axis) at 0.5 kHz (left) and 1 kHz (right). Values of y intercept of the regression is 20 while slope is 0.8

The differences of threshold between PTA and ABR in relation to the audiological situation (NH, SNHL and CHL) are reported in Table 2. According to the linear regression analysis, differences at 0.5 and 1 kHz are larger in normal hearing subjects and become smaller in the presence of hearing loss. These differences are significant at the ANOVA test of variance ($p < 0.0001$) but only the normal group differs from the others at Bonferroni's test. Therefore PTA and ABR threshold differences are not related to the kind of hearing loss, but rather the existence or not of a hearing impairment.

Table 2

PTA and ABR mean thresholds and mean differences between the two tests in relation to the auditory function and the kind of pathology (sensorineural vs. conductive)

	Normal		**SNHL**		**CHL**	
	0.5 kHz	**1 kHz**	**0.5 kHz**	**1 kHz**	**0.5 kHz**	**1 kHz**
PTA	8 (5)	8 (4)	46 (12)	52 (16)	64 (9)	61 (9)
ABR	26 (9)	27 (4)	54 (14)	60 (14)	68 (8)	70 (9)
Difference	18 (8)	19 (5)	8 (8)	8 (6)	4 (7)	9 (8)

Standard deviation values are reported in brackets. Differences at Bonferroni's test are significant only as regards the normal group toward the two pathological groups

Discussion

The introduction of new techniques for an objective and frequency-specific assessment of hearing function could help solving important health problems. There could be improvements in early detection and treatment of hearing loss in infants and newborns and in objective diagnosis of professional hearing impairments in Occupational Medicine. The brain responses elicited by brief auditory stimuli (clicks) or transient auditory evoked potentials (AEP) are useful tools for objective diagnosis of hearing impairment, as already proven [*13*], however these techniques have some disadvantages. Brief acoustic stimuli are not frequency specific thus we cannot evaluate precisely the residual hearing, namely assessing thresholds at different frequencies [*3*].

Pure tone stimuli used for traditional audiometry, with long rise and fall times, are inappropriate for ABR, above all at low frequencies, because they are too slow to generate an onset response.

A stimulus used for ABR that represents a compromise between the desired frequency specificity and the required temporal brevity is the short duration tone burst (also termed tone pip). These stimuli are very brief tones with rise/fall times of only a few cycles and brief or no plateau. The so-called “2-1-2” tone burst, which consists of 2 cycles of the tone in the rise/fall and 1 cycle in the plateau, is often used. The rise/fall time of the tone burst can be shaped with a non-linear gating function such as Blackman or cosine window to reduce spectral splatter. Such tone burst stimuli are more confined in their frequency range than clicks, but they are considerably broader than the stimuli used for pure tone audiometry. However, whether this actually enhances ABR frequency specificity is questionable. For example, Purdy and Abbas [*11*] showed no significant differences in ABR thresholds in hearing impaired subjects using Blackman versus linear windows at high frequencies.

The predictive accuracy of TB-ABR has been studied extensively by Stapells and colleagues [*16*, *17*] in populations of normal and hearing impaired infants, children, and adults. They used tone bursts with linear rise/fall times, at frequencies between 500 and 4000 Hz, presented with notched noise to enhance frequency specificity. The authors found similar results for all age groups. About 98% of ABR thresholds were within 30 dB of pure tone behavioral thresholds, 91–93% within 20 dB, and 66–69% within 10 dB. The average ABR threshold was about 10 dB worse for 500 Hz tone bursts than for higher frequencies. With regard to children these rather limited differences were most often observed with auditory test performed at dissimilar ages, ABR being generally carried out many months before behavioral testing [*18*].

Our data support Stapells’ et al. results and confirm that Blackman window generates an acoustic stimulus capable of originating reliable responses even at low-mid frequencies. Therefore subtracting 10 dB (SD 8.1), which is the mean difference between PTA and ABR thresholds, from ABR threshold could give an acceptable approximation of the corresponding PTA threshold.

In addition to this the results obtained demonstrate that the margin of error is larger in normal hearing and smaller in hearing impaired subjects, not depending on hearing loss type (sensorineural vs. conductive). Consequently auditory recruitment is not responsible for these differences in our sample. The linear regression allows creating a model of prevision of the ABR threshold on the basis of PTA threshold; according to this model (Fig. 2), the error reduces as hearing loss gets worse. Therefore this error is scarcely relevant to pediatric population, since normal hearing babies will not need an assessment of their hearing levels as accurate and precise as hearing impaired patients. On the contrary the error does not meet the requirements of accuracy of forensic medicine.

This relation between PTA and auditory evoked potential thresholds, which get similar to each other as hearing loss gets worse, has been already observed in ASSR [*8*] and slow-vertex response audiometry [*14*, *15*]. We do not have a definitive explanation for this pattern. It is certainly not related to recruitment since we evaluated the responses at threshold level and it was also present in conductive hearing loss. In a previous paper we stated that it could be explained by higher risk of mistaking wave V identification at threshold, when the number of tracings to define the threshold increases [*14*, *15*].

A known disadvantage is that the broad morphology and poor repeatability of the ABR to low frequency stimuli can make it difficult to identify wave V [*16*] especially at low intensities, and considerable experience is necessary to accurately evaluate low frequency ABR thresholds in clinical setting. These difficulties are confirmed in this study by the waveform atypical pattern in which mean latencies of wave V were 9.44 ms at 0.5 kHz and 9.01 at 1 kHz.
An alternative way to enhance frequency specificity of ABR is to combine the tone bursts with notched noise masking presented to the same ear [*16*, *19*]. Notched noise is similar to wide band noise, containing energy across the frequency spectrum, except within a certain narrow range of frequencies (notch). The notch frequency corresponds to the frequency of the tone burst used. Thus, the sidebands of energy present in the tone burst are masked out, restricting the area of stimulation to the nominal frequency of the tone. This assures that the ABR is generated by neurons sensitive only to the tested frequency.
In conclusion the tone burst ABR can be considered a valid tool to predict the threshold at low frequencies, in case of suspected hearing loss; however, further studies are recommended to evaluate an ipsilateral masking such as notched noise to ensure greater frequency specificity.

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