A Novel Method of Brainstem Auditory Evoked Potentials Using Complex Verbal Stimuli

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Abstract

Background: The click and tone-evoked auditory brainstem responses are widely used in clinical practice due to their consistency and predictability. More recently, the speech-evoked responses have been used to evaluate subcortical processing of complex signals, not revealed by responses to clicks and tones. **Aims:** Disyllable stimuli corresponding to familiar words can induce a pattern of voltage fluctuations in the brain stem resulting in a familiar waveform, and they can yield better information about brain stem nuclei along the ascending central auditory pathway. **Materials and Methods:** We describe a new method with the use of the disyllable word "baba" corresponding to English "daddy" that is commonly used in many other ethnic languages spanning from West Africa to the Eastern Mediterranean all the way to the East Asia. **Results:** This method was applied in 20 young adults institutionally diagnosed as dyslexic (10 subjects) or light dyslexic (10 subjects) who were matched with 20 sex, age, education, hearing sensitivity, and IQ-matched normal subjects. The absolute peak latencies of the negative wave C and the interpeak latencies of A-C elicited by verbal stimuli "baba" were found to be significantly increased in the dyslexic group in comparison with the control group. **Conclusions:** The method is easy and helpful to diagnose abnormalities affecting the auditory pathway, to identify subjects with early perception and cortical representation abnormalities, and to apply the suitable therapeutic and rehabilitation management.

Keywords: Auditory brainstem responses, Complex auditory brainstem responses, Speech stimuli

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Introduction

Auditory brainstem responses (ABRs) provide sensitive non invasive neurophysiologic method for recording of electrical events that occur along the auditory pathway of the brainstem.[1] Simple stimuli such as clicks or tones have been widely used, so far, in clinical practice in the evaluation of auditory pathway integrity in many diseases affecting synaptic activity. Indeed, in a very recent paper, it was found that diabetic patients have an early involvement of central auditory pathway that can be detected with fair accuracy with auditory brainstem responses.[2] However, these non-speech stimuli do not provide insight about the actual processing of speech sounds. Therefore, more complex stimuli or complex auditory brainstem responses (cABRs), such as speech and music, have been used recently.[3] So far, the monosyllable speech stimulus "da" corresponding to the first syllable of the English word "daddy" has been used experimentally [4] We have already used the speech stimulus "ma" which is the first syllable of Greek "mama" corresponding to English "mammy" and we have found a number of significant differences in the onset response in young adults with dyslexia when compared to their normal counterparts.[5] Such disyllable stimuli corresponding to familiar words induce a pattern of voltage fluctuations in the brain stem resulting in a familiar waveform, yielding better information about brain stem nuclei along the ascending central auditory pathway.

Therefore, we have used for the first time, a new method of artificial successive complex stimuli "baba". The disyllable word "baba", contains frequencies[6] closer to

"da" than "ma" and has components acoustically similar to "da". Furthermore, the word "baba", which means father, is used also in many ethnic languages such as Arabic, Chinese, Slavic, Turkish, and in other languages spanning from West Africa to the Eastern Mediterranean all the way to the East Asia.

Materials and Methods

Stimulus selection, duration, presentation

The selection of stimulus depends mainly on the population being studied and the specific research questions we have in hand. During the piloting phase, several different stimulus tokens should have been used to determine whether robust and reliable cABRs have been obtained.[7] A summary is provided[7] in Table 1. In our experiments, the duration was 170 ms. Because of the sheer number of stimulus presentations required to obtain a robust response, there is an obvious tradeoff between stimulus duration and length of the recording session. In order to record 6000 trials to a synthesized 50 ms /ba/ takes approximately 9 minutes, assuming an interstimulus interval (ISI) of 50 ms. Because each consonant-vowel pair has a unique formant transition, the steady-state vowel can be removed with little impact on the percept. Stimulus duration greatly affects pitch because lower frequencies have longer periods than higher frequencies (e.g., a 20-ms stimulus can have no meaningful frequency representation under 50 Hz). This section covers topics relating to stimulus presentation including stimulus intensity; monaural and binaural stimulation; left and right ear stimulation, stimulus polarity, stimulation rate; transducers (i.e., earphones, loudspeakers); jitter in the stimulus presentation, and multiple stimulus conditions[7] [Table 2].

Transient and sustained characteristics

In the case of speech syllables, transient features include the onset of the sound, and the offset of sound. Within the classes of speech sounds, obstruent stop consonants (e.g., /d/, /b/, /k/) have, by definition, sharper stimulus onsets than nasals and glides (e.g., /m/ and /y/, respectively) and produce more robust onset responses.[4-6] In order to obtain strong sustained responses, the cABR stimulus should have a low pitch with a fundamental frequency (F_0) in the range of 80-300 Hz. While speech can contain spectral information up to 10 kHz, the spectral information necessary for distinguishing different consonants and vowels is largely below 3000 Hz.[7]

The use the word "baba"

We have used the word "baba" for the following reasons: First, the word "baba" corresponds to English "daddy", consists of two repeated "ba" and is used in many

other languages. Thus, we use verbal acoustic stimuli consisting of broad band syllabus "baba" with fast rise, plateau, intersyllabus, and fall time replacing the already well-established "da" for similar studies with English speaking subjects.[3,7] Second, the sound consists of a transient segment followed by a sustained periodic segment. It is, in a sense, much like a click followed by a tone—two acoustic signals whose brainstem response properties have been extensively characterized. Third, stop consonants pose great perceptual challenges to clinical populations such as the hearing- and learning-impaired. All stimuli were created in a digital speech synthesizer. The acoustic properties of stimulus had to be checked with a sound analyzer before proceeding with the experiment. To confirm that the stimulus meets the desired specifications, the synthetic sound was acoustically analyzed in Praat[8] The final recordings were analyzed and the peaks named in the same way as those of well-established[6] cABRs.

Complex auditory brainstem recording collection

A PC-based stimulus delivery system controlled time of delivery, stimulus sequence, and stimulus intensity,

Table 1: Stimulus characteristics for cABRs

Parameter	Settings	Rationale
Type	speech ("ba-ba")	examine how behaviorally-relevant sounds are turned into neural code
Transient	strong attack and amplitude burst	maximize transient responses
Sustained	F0 < 500 Hz	maximize sustained responses
Creation	synthetic	cABR stimuli created with Praat (speech synthesizer) software package
Duration	short: 50 ms	minimizes recording time
	long: 200 ms	maximizes naturalness

Table 2: Stimulus presentation parameters for cABRs

Parameter	Settings	Rationale
Intensity	above threshold: 80 dB SPL	Automatic sound level meter
Binaural Stimulation	For better response characteristics	more realistic than monaural
Transducer	magnetically shielded ear inserts	Exclude stimulus artifact
Rate and ISI	rate: dependent on stimulus duration	See table 3 for recording-based issues that impact rate and ISI decisions
	ISI: >= 30% of stimulus duration	
Presentation Software	perform thorough testing to ensure precise, non-jittered stimulus presentation	because of the temporal sensitivity of the cABR, a small amount of jitter will spoil the response

and triggered the PC-based evoked potential averaging system. All electrode impedances were <5 kOhms. Reproducibility of the results was always achieved. The cABRs were collected, in response to a click (0.1 ms) and randomly presented alternating polarities of "ba". cABRs were differentially recorded from Cz-to-ipsilateral earlobe, with forehead as ground. The sampling rate was 20,000 Hz. Responses were bandpass filtered on-line from 100 to 2000 Hz. Sweeps with noise levels which exceeded ± 30 μV were rejected from the average. Three repetitions of 1000 sweeps each were collected in response to the click as well as for each polarity of "ba". The click stimuli were presented at 80 dB SPL with an inter-stimulus interval (ISI) of 32 ms; the recording window was 20 ms, including a 10-ms pre-stimulus period [5] The "ba" stimuli were presented at 80 dB SPL with an ISI of 51 ms; the recording window was 160 ms, including a 10-ms pre-stimulus period (sum 170 ms).[9]

Complex auditory brainstem recording analysis

The latencies of the click-evoked waves I-V and the negative peaks following stimulus "baba", marked A and C, were compared to normative values [Figure 1]. Issues relating to electrodes, filtering, sampling rate, signal averaging, simultaneous ABR-cortical EP recording, artifact reduction, and recording conditions are summarized[7] in Table 3.

Results

Our method has been already applied in 20 institutionally diagnosed young adults with learning disabilities after thorough audiologic examination including speech reception threshold testing, pure-tone audiometry, speech discrimination testing, and tympanometry.[6] Twenty age-, sex-, education-, hearing sensitivity-, and IQ-matched healthy young adults constituted the control group. Absolute peak latencies of the negative wave C and the interpeak latencies of A-C elicited by verbal stimuli "baba" were significantly increased in the dyslexic group in comparison with the control group. In a subgroup of 10 light dyslexic patients, no significant delays were found in peak latencies A and C and interpeak latencies A-C in comparison with the control group.

Discussion

This method shows that acoustic representation of speech sound of word "baba" exists as low as the auditory brainstem and ABRs are delayed in subjects with learning disabilities. The monosyllable "ba" was used, for the first time instead of "da", because when it pronounced successively creates the word "baba", with meaning "father" that is used in several languages
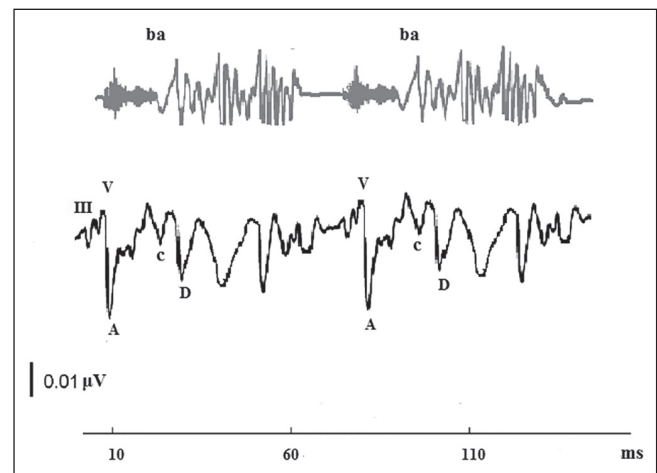

Figure 1: cABRs representation of a 160 ms to /ba/ba stimulus (upper) and time-matching response (lower) including peaks III, V, A, C, D that relate to major acoustic landmarks of the stimulus and with neural transmission time between cochlea and brainstem. Microvolts refer to the response

Table 3: cABRs recording parameters		
Parameter	**Settings**	**Rationale**
Electrodes	vertical montage (active Channel: Cz; reference: earlobe(s); ground: forehead)	rostral brainstem recordings;
Sampling Rate	20000 Hz	better temporal precision with the higher sampling rates
Filtering	low pass cutoff: 2000-3000 Hz	transient peaks
	high pass cutoff: 30-100 Hz	depends on spectral characteristics of stimulus
Signal Averaging	2000 sweeps	To determine response replicability
Averaging Window	begin 10 ms before stimulus onset	an adequate sample of the baseline is needed to determine whether a particular response peak is above the noise floor
		for running window analyses: The pre-stimulus time window should be > or = to the duration of the analysis window
	extend 50 ms after stimulus onset	neural activity return to baseline but next recording include activity of efferent signals
Minimize artifacts	passive collection protocol	For myogenic artifacts
	electromagnetically shielded insert ear phones	for stimulus artifact

which cover more than half of the world population. Furthermore, it has components acoustically similar to "da". So far, the literature on speech-ABRs has included speakers of different languages, including English, French, Catalan, Spanish, Greek, Persian, and Hindi [10] For native speakers, differences might be in brainstem processing for the short syllable "da". By using our method, such differences will not exist since syllable "ba" and especially in a successive way the word "baba" is commonly used in many other countries.

Approximately 9% children in the United States have reading and learning problems.[11] Therefore, this method could be applied in understanding effects of peripheral hearing loss on processing of speech sounds, in children and adults with auditory processing problems. Studying the processing of speech sounds at the brainstem may provide knowledge regarding the central auditory processes involved in normal hearing individuals and also in other clinical populations as they incorporate parts of central processing and efferent recognition process of auditory signals. Furthermore, cochlear implants, hearing aids, plasticity of the auditory system, presbycusis, and acoustic neuropathy can be also evaluated. Our method can be also used in identifying children at risk for acoustic-based learning problems and dyslexia before they reach at school age.[12] This can help to identify subjects with acoustically based learning problems and apply early intervention, rehabilitation, and treatment. Certainly, careful normal values are needed in order early screening to be reliable.

The subjects we studied had already subjected to some kind of training due to their age and for this reason we believe that our findings represent a sound propagation problem in dyslexia. Other studies, however, have postulated a pure top-down modulation of signal input due to faulty phonemic awareness.[13]

Further extended research is needed to reveal the advantages or possible weaknesses of the proposed method, even if preliminary results are promising, in order to be updated and refined for future applications.

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