Original Article

A Study of the Effect of Two Meaningful Syllables Stimuli in Auditory Brainstem Responses Using Correlation and Coherence Analyses

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ABSTRACT

Purpose- In elementary studies on brainstem evoked potentials a simple stimuli like click and sinusoidal tones is used, but in recent years Auditory Neuroscience oriented to use complex stimuli. These complex stimuli (e.g. speech and music) are more capable in representation of auditory pathway functions. Previous studies in this field, mainly attend to one single vowel or consonant-vowels. Until now no study has been done which considered the encoding of multi structurally meaning full combination of consonant-vowel. In this study, we try to extract information using suitable tools from Auditory Brainstem Responses (ABR) to stimuli 'baba'.

Methods- At the first step we used a test to find an appropriate distance between two consecutive consonant- vowels 'ba' which is perceived 'baba'. For this, a psychophysical test was designed. Subjects were asked to choose a suitable distance between two 'ba' that the combination perceived 'baba'. After recording evoked potentials to 'ba' and 'baba', we searched distinctive features between the signals related two stimuli. So at first, we began with comparative time-frequency analyses like correlation and coherence.

Results- Correlation analyses show that the response to 'ba' and the response to first syllable of 'baba' in the Onset and also transient parts of responses are different and the response to first and second syllable of /baba/ become similar. The results of coherence analyses show that these differences could not be represented with a linear relation merely.

Conclusion- Brainstem neural activity was different in countering with single syllable stimuli in comparison with meaningful disyllabic stimuli. These changes can be consequences of activities in anatomical top-down pathway.

1. Introduction

Auditory evoked potentials are the electrical responses of auditory system (ear, auditory neurons or brain regions related to auditory) to acoustic stimuli [1]. In 1970, researchers found out that auditory brainstem response (ABR) can be recorded using surface electrode from scalp [2]. ABR is generated by instantaneous activities of auditory neurons driven by external stimulus.

Primary studies on auditory brainstem responses consider simple stimuli like click and sinusoidal tones, also these stimuli are appropriate to investigate overall auditory processing conditions but they cannot explain how auditory pathway is processing the sounds, when encounter to natural sounds and not synthesized in the laboratory like music, speech and Ambient sounds [3]; because of these reasons, for a better understanding of auditory processing

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pathway in the recent years auditory neuroscientists switch to use complex sounds like speech and music as stimuli.

Using speech stimuli rather than non-speech stimuli has considerable benefits; auditory system has complex and nonlinear behavior so to investigate how an auditory system encodes speech cues, it is necessary to use speech stimuli to excite the auditory pathway [4-6]. Because of long term confrontation with the speech phonemes and language experiences, the function of auditory pathway and speech representation in the neural system could not be explored with simple stimuli [6, 7].

For the first time, using complex sounds in recording auditory brainstem responses (cABR) was introduced by Greenberg in 1980 [8]. The history of using stimuli began with simple stimulus vowels [9-13] and continued later to complex stimuli like consonant-vowels like 'ga', 'ba' and 'da' [1]. One of the most commonly used stimuli was 'da' [3-5, and 14-16] some of the studies move their tendency from a single syllable to a complex one like 'dani', 'rose' and 'car', even though some phrases like 'chicken pot pie' [17, 18]. In 2013, Kouni, *et al*. [19, 20] suggested to use 'baba' as stimuli, they claimed that using a meaningful two-syllable stimuli causes generating a pattern of voltage fluctuations in the response which represents appropriate information about the kernels of brainstem in the bottom up pathway.

In above studies on complex stimuli like words, only the existence of signal and overall morphology of response was checked. Up to now, no study was done to consider multi-syllable contains structurally combining consonant-vowel which constructs a meaning-full word and how these syllables encode in auditory pathway. Studies on auditory evoked potential related to speech perception attend to cortical responses, and they did not consider to influence the brainstem function in speech perception [21].

Existence of abundant anatomical feedbacks from cortex to different parts of brainstem whose function are not clear yet [22] causes to create this idea that these recursive paths through the top-down control process in the brain can influence the brainstem function like feedback loops.

In this study, first, we looked for a definition of structural combination of two consonant-vowel 'ba' which constructs a meaning-full 'baba'. Then, feature extraction was done by using an appropriate tool and analyses from the evoked potential to 'ba' and 'baba'. The reason for selecting 'ba' and 'baba' was their universality (existing in most of alive languages of world) of 'ba' and 'baba' and also 'baba' has meaning in most of languages (means 'father') like Greece, Chinese, Arabic, Persian, Turkish, Slavic and most of native languages in the geographic area between west of Africa, Mediterranean and east Asia [19, 23].

'baba' can be simply constructed with the combination of two 'ba', but the important question outstands here: how much the time interval between two consecutive 'ba' should be which the stimuli was perceived 'baba'? If the interval of two consecutive 'ba' is chosen too small, the two syllables merge and 'baba' is not perceived and if the interval is too long, the two syllables are heard and perceived separately. To answer this question we designed a test based on Psychophysical sciences methods. Psychophysics tries to explore the quantitative relations between stimuli and the impression of perception [25].

2. Materials and Methods

2.1. Subjects

28 volunteer students from Tehran University of medical sciences (15 women and 13 men), aged from 22 to 29 years (mean ± SD = 24.34 ± 1.95), participated in this study. None of the subjects had a history of auditory, learning or neurologic problems. All students were monolingual Persian speakers by self-report and pure tone hearing thresholds for both their ears were equal to or better than 20 dB HL for octave frequencies 250–8000 Hz. Subjects signed the written consent to participate intensively in the study. All procedures were approved by the deputy of research review board and ethics community of Tehran University of Medical sciences.

2.2. Psychophysical Task

In the previous studies about auditory evoked to 'ba', the duration of stimuli was chosen 170 ms [1, 24]. This duration is too small and causes difficulty in hearing; therefore, we used longer stimuli with duration of 220 ms, which the consonant and transient part of stimuli is completely the same as 'ba' with 170 ms duration and only the duration of vowel part (sustained part of 'ba') was extended. The longer 'ba' is clearly perceived 'ba'.

For finding suitable distance between two /ba/ syllables regarding its perceptual content, MATLAB version 14.1 was used to develop a graphic user interface (GUI). This GUI played 2 consonant vowel (CV) /ba/ with a certain distance and asked from participants to reduce or increase the silent duration between these two CV. This trial continued until they ensured that they were hearing meaningful /baba/.

For eliminating person's assumption effect, there were two modifying options in GUI including fine tuning and gross tuning. Participants are blind to the exact amount of tuning they do in each step. But they just know the gross tuning tool adjusts distance in longer steps.

Each subject did this task in 4 trials. The average of each person's response was calculated and mentioned as his/her response. The advantages of repeating this experiment include: 1- eliminating transient variables effecting in the responses. 2- Variance of Results for each person can be used as an index of his/her reliability of answering.

After recording these data, those subjects that were outlier eliminated from dataset because of their large variance. An appropriate distance that satisfies statistical analysis of these results was selected and tuned as a fixed distance for generating /baba/ in further steps of this study.

2.3. Analysis of cABR Signals

Correlation was performed as a time domain analysis and coherence as a time frequency analyses for comparing cABR results.

The cross correlation function of two signals, gives a measure of the similarity of two signals defined as below:

$$C_{xy}(\tau) = \int_{-\infty}^{\infty} x(t)y(t+\tau)dt \tag{1}$$

The correlation is an appropriate tool for comparing time domain representation of 2 signals (for instance comparing stimuli and response). The correlation is a function of lag. It can be used also for finding time delay between two signals. Because of fidelity cABR responses to stimuli, the onset of responses can be determined from cross correlation of stimuli and response where C_{xy} has maximum value at onset time. And also the Signal to Noise Ratio (SNR) can be determined from their cross correlation value at the lag of zero. It can also be used for finding response changes relating to changes in stimuli specifications. In the other hand, cross correlation was used for cABR analysis in previous studies [23, 24]. Besides, autocorrelation was used for finding repetitive structures of cABR [25].

For investigation of mutual behavior of two signals, coherence analysis can be used [26, 27]. It is calculated based on Fourier spectrum estimation. Coherence term generated from Latin term Cohaerentia, which means relation or natural compatibility [26]. Coherence function finds common frequencies in two signals and calculates signals similarity in frequency domain.

Coherence function [28] defined as:

$$C_{xy}(\omega) = \frac{P_{xy}(\omega)}{\sqrt{P_{xx}(\omega)P_{yy}(\omega)}} \tag{2}$$

where P_{xx} and P_{yy} are power spectrum of x and y respectively and P_{xy} is cross power spectra, and ω is frequency. Power spectrum and cross power spectra is defined as:

$$P_{xx}(\omega) = |X(\omega)|^2 = X(\omega)X^*(\omega)$$
$$P_{xy}(\omega) = X(\omega)Y^*(\omega) \tag{3}$$

where * shows complex conjugate, X and Y are Fourier transform of x and y respectively.

$$X(\omega) = \int_{-\infty}^{\infty} x(t)\, e^{-ti\omega} dt \tag{4}$$

The coherence function can be used as similarity measures of two signals in frequency domain. For linear relating signals without noise this parameter equals 1 in all frequencies, and for two signals with nonlinear relation this amount goes toward 0 [28, 29].

3. Results

In Figure 1, final result of 25 remained participants in psychophysical test is shown. Every column is a representative of person's average responses in four tests and red dash line shows the average response from all participants.

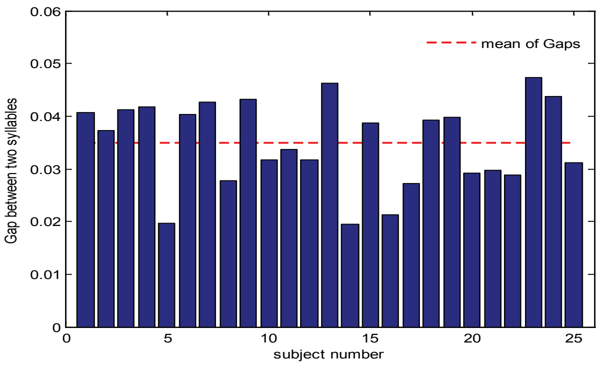

Figure 1. Final result of in psychophysics test.

The average of all participants responses was 35 ms with standard deviation of 8 ms. A reasonable range of intervals between two syllables that participants could choose as a fair interval was 0-100 ms. According to this issue, results show that 35 ms could be chosen as the delay between two syllables with single consonant-vowel structure that was understood as a unit /baba/.

Using the results of this test the proper stimulus /baba/, was constructed and used in the recording evoked response potential process. The grand average of 25 subject responses to /ba/, the response to the first syllable and, and the response to the second syllable of /baba/ are shown in Figure 2.

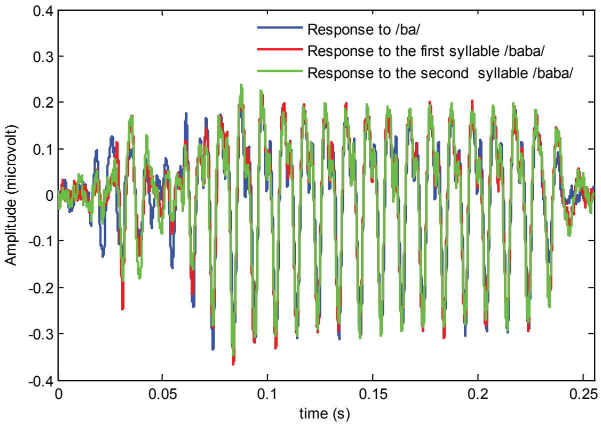

Figure 2. The response to /ba/ and the responses to syllables of /baba/.

According to Figure 2, it seems that responses within the steady segment (that are response to vowel parts of stimuli), are not too far from each other and the only difference is seen in the initial of the response (that is response to consonant part of stimuli). Figure 3 shows the first 100 ms of response in order to focus closely with magnification.

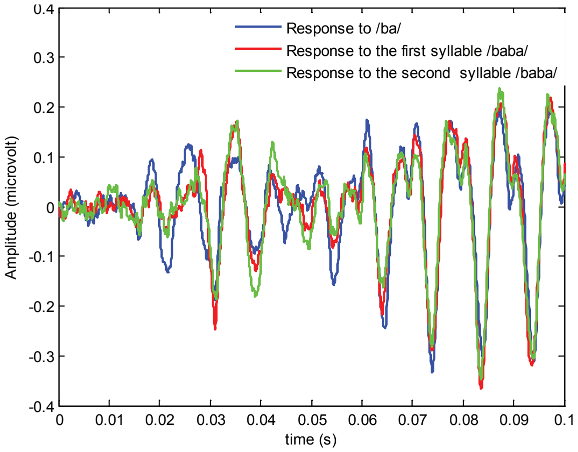

Figure 3. First 100 ms of response to /ba/ stimulus and response to syllables of /baba/ stimulus.

According to the morphology of signals, it seems the responses of two syllable /baba/ are similar and particularly the first parts of the responses become different from the response to stimulus /ba/. This difference is an approval delay of some peaks and amplitudes increasing in peaks related to onset response.

For having more accurate signal analysis, we investigated those with autocorrelation. In below Figure the autocorrelation of signals in time windows of 400 samples (20 ms) and window shift steps of 20 samples (about 1ms) was calculated.

The results of these autocorrelations have been presented in Figures 4 to 6 by two dimensional maps through time and lag.

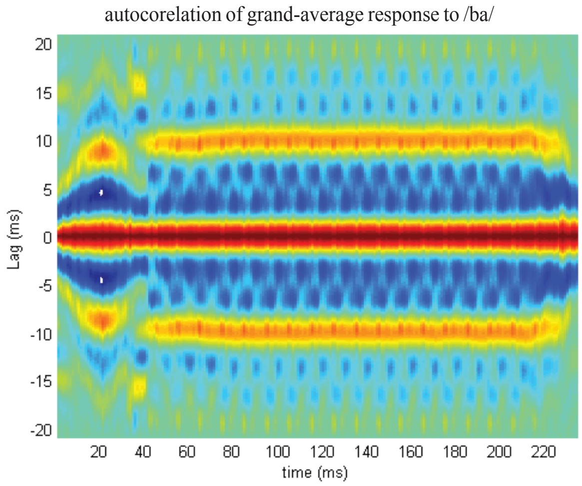

Figure 4. Autocorrelation of grand average to /ba/.

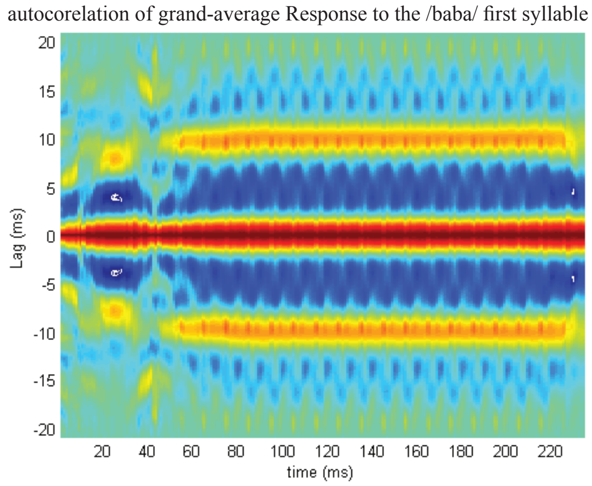

Figure 5. Autocorrelation of grand average to the first syllable /baba/.

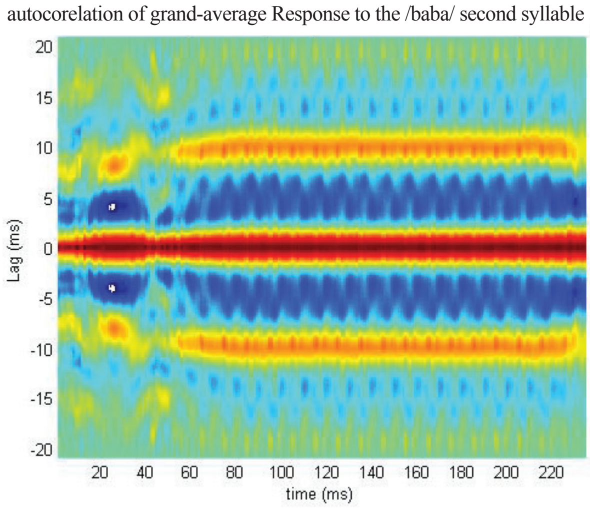

Figure 6. Autocorrelation of grand average to second syllable of /baba/.

A preliminary study by the correlation analysis shows that signals are not different in vowel response parts and in parts related to consonant response, the pattern of response delay of the signal components are similar but not identical. It seems that these patterns were followed more accurately in the /ba/ response.

For analyzing the magnitude of the response to /ba/ and the response to /baba/ in different frequencies, we used coherence between responses in the time windows of 400 samples (20 ms) with Progressive step of 20 samples (1 ms).

Figure 7 illustrates the coherence analyses of the response to /ba/ and the response to the first syllable of /baba/. The coherence between the response to /ba/ and the second syllable of /baba/ was shown in Figure 8, and Figure 9 shows the coherence of the response to first and second syllable of /baba/.

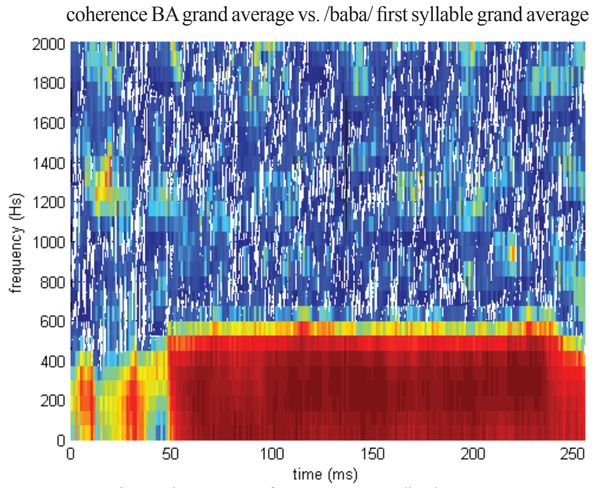

Figure 7. The coherence of response to /ba/ vs. response to /baba/ first syllable.

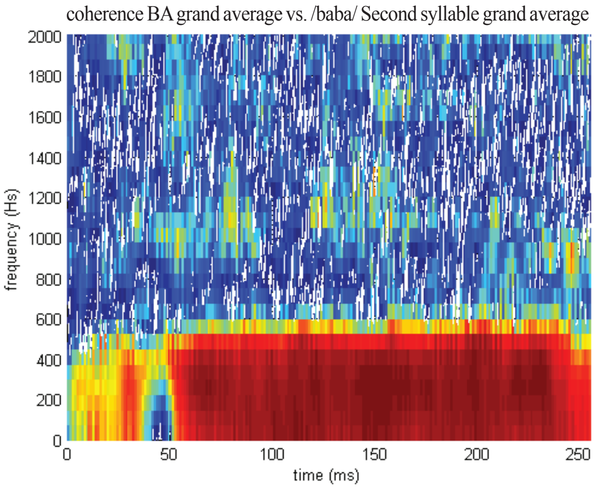

Figure 8. The coherence of response to /ba/ vs. response to /baba/ second syllable.

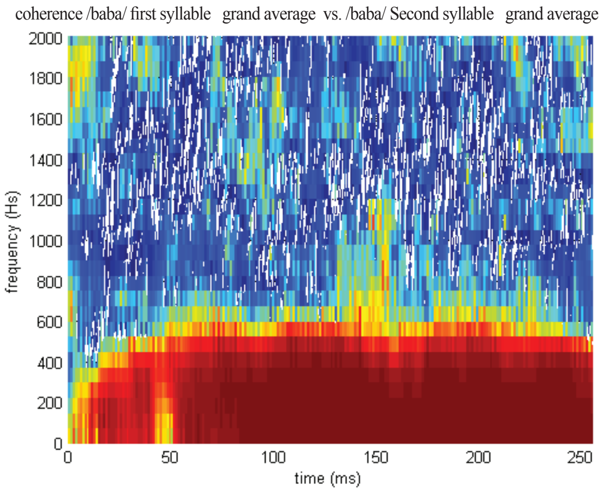

Figure 9. The coherence of response to first syllable second syllable of /baba/.

It can be seen that, in all three Figures of coherence Analysis (Figure 7-9), after 60 ms the coherence is high. In the case of response to first syllable vs. response to second syllable of / baba/ (Figure 9) the coherence before 60 milliseconds is also high. But Figures 7 and 8 show the coherence response to /ba/ vs. response to syllables /baba/ are in the lower range.

4. Discussion

The purpose of this study was to investigate the changes of evoked signals to meaningful disyllabic stimuli in the subcortical responses. In previous researches, mostly single syllables stimuli is used and less study attended to word stimuli. In [18] response to meaningful words was compared to its inverse form (meaningless). In [19, 20] /baba/ was used as a meaningful word stimuli because of the more validity in analyzing auditory pathway. However, properties of response to a meaningful word which composed of some basic universal like /ba / is not analyzed until now.

The analysis of the shape of signal shows this difference between single and disyllabic stimulus. Time analysis of morphology of these responses indicated that the response of the stimulus like / baba/ as a meaningful word was different in the latency and consistency with stimulus such as / ba/. This difference is the biomarker of language experiences which causes changing in the auditory system function in the sub-cortical. Correlation and Coherence Analysis were used for a closer look to these responses. The results indicated that the system dynamic was different in countering with single syllable stimuli in comparison with disyllabic stimuli. Coherence values for each pair were close to one after 60 ms and the frequencies below 600 Hz which represented a linear relationship between responses to /ba/ and /baba /, but a decrease in the amount of coherence can be observed before 60 ms , which represented a failure of linear relationship and similarities between two responses.

Comparing the coherence of the responses to each syllables of /baba/ before 60 ms of responses expresses high similarities and relationship in this time interval. Results of these analyses of coherence show that the differences cannot be represented only on the basis of a linear relationship such as phase lag and variation in frequency amplitude and more complex dynamics are involved to change auditory system behavior.

The changes of sABR signals in response to meaningful disyllabic stimulus indicates that brainstem contributes in high level cognitive functions of auditory perception. These observed changes can be linked to the top-down modulation of brainstem nucleus by the auditory cortex.

The results of this paper will help to identify the auditory pathway function much better and can be applicable in various fields such as design and development of algorithms for tuning cochlear implant based on signal properties of healthy people and evaluating the function of auditory pathway in people with cognitive disabilities.

It is suggested that in the future, studies can use nonlinear analysis for investigating the differences in the dynamics of the disyllabic stimuli in the auditory system. One can use a disyllabic stimulus such as /baga/ vs. /baba/ for investigating the effect of meaning in the processing of subcortical speech.

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