Original Article

# Binaural Interaction Component in Speech Evoked Auditory Brainstem Responses

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**OBJECTIVE:** This article aims to describe the characteristics of the binaural interaction component (BIC) of speech-evoked auditory brainstem response (ABR).

**MATERIALS and METHODS:** All 15 subjects had normal peripheral hearing sensitivity. ABRs were elicited by speech stimulus /da/.

**RESULTS:** The first BIC (BIC-SP1) in the speech-evoked ABR occurred at around 6 ms in the region of peak V. The second BIC (BIC-SP2) was present around 8 ms in the latency region of peak A. The third and fourth BICs of speech-evoked ABR (BIC-SP3 & BIC-SP4) were observed at around 36 ms and 46 ms, respectively, in the latency regions of peaks E and F, respectively. BIC-SP1 and BIC-SP2 were present in all subjects tested (100%), whereas BIC-SP3 and BIC-SP4 were present in 11 (73%).

**CONCLUSION:** Because ABRs are not affected by sleep and mature early, this tool can be evaluated in identifying binaural interaction in younger and difficult-to-test populations.

**KEYWORDS:** Binaural interaction component, auditory brainstem response, speech, latency, amplitude

## INTRODUCTION

The binaural interaction component (BIC) of auditory brainstem responses (ABR) has been a subject of investigation since the 1970s. Jewett [1] first suggested BIC of ABR in cats occurring at the latencies of waves IV and V. He found that when both ears were stimulated together (binaural condition), the amplitudes of the first three ABR peaks were equal to the summed amplitude of responses from the right and left ears stimulated separately. Amplitudes for peaks IV and V of ABR, however, were smaller in binaural stimulus mode compared with the sum of monoaural amplitudes. Since then, BIC has been successfully demonstrated in guinea pigs [2-3], dogs [4], and humans [5-7]. BIC of ABR is generally analyzed in terms of binaural difference waveform. In algebraic terms, BIC is computed as BIC=(R+L)−B, where B is the response waveform evoked by the simultaneous excitation of both ears and R and L are the responses evoked by monoaural excitation of the right and left ears, respectively [2]. BIC is thought to reflect the activity of neurons specifically tuned to binaural stimulation.

Deficits in binaural processing can lead to different degrees of auditory processing disorders (APD). Assessing binaural interaction is of diagnostic importance especially in children with suspected APD. Usually, binaural interaction is measured in clinical settings using behavioral tests such as masking level difference, dichotic tests, and/or binaural fusion tests. However, these behavioral tests are difficult to conduct on young children. Moreover, extra auditory factors such as attention and lack of cooperation can affect the results of behavioral auditory processing tests. Hence, the objective measures of auditory processing are necessary. BIC of ABR is proposed to be an objective test in assessing binaural hearing. Moreover, BIC of ABR may help in studying the neural correlates of some binaural psychoacoustic phenomenon such as localization, hearing in noise, and binaural summation. Gopal et al. [8] measured BIC of click-evoked ABR in nine children with suspected APD. They reported a significant reduction in the amplitude of BIC occurring around the latency region of peak V in children with suspected APD. Delb et al. [9] studied the sensitivity and specificity of BIC of ABR in identifying children with APD on a larger group of subjects. Their results showed that BIC of ABR can be used as an indicator of APD, with a sensitivity and specificity of 76%. However, when present, the amplitudes and latencies of BIC of ABR showed a high degree of overlap between a normal group and APD group; hence, they concluded that the latencies and amplitudes of BIC cannot be used as a diagnostic criterion to identify individuals with APD.

Conventionally, brief and rapid stimulus (i.e., clicks or tone bursts) have been employed elicit ABR as well as BIC. ABR evoked by speech stimuli follows the temporal features of the input signal. Speech-evoked ABR is described in terms of an onset response

and frequency following response (FFR). Both amplitude and latency deviances in onset response and FFR of speech-evoked ABR have been linked to abnormal perception and linguistic abilities. King et al. [10] noted that a subgroup of children with learning problems had normal latencies on click-evoked ABR, whereas delayed onset and FFR latencies for ABR evoked by /da/ stimuli. These findings suggest that speech-evoked ABR may be a better candidate to assess auditory processes than click-evoked ABR. Therefore, we hypothesized that BIC evoked by speech stimuli may be a more sensitive and objective tool to assess binaural interaction than click-evoked BIC.

## MATERIALS and METHODS

### Participants
Fifteen participants (7 males and 8 females) aged 17–25 years participated in the study. All subjects had pure tone hearing sensitivity within 15 dB HL at frequencies from 250 Hz to 8000 Hz for air conduction and from 250 Hz to 4000 Hz for bone conduction. Furthermore, all subjects had an "A"-type tympanogram with ipsilateral reflexes at normal sensation levels in both ears. From a structured interview, it was ascertained that none of the participants had any otological or neurological disorders, history of ototoxic drug usage, or noise exposure. Auditory processing disorder checklist was administered; those who passed the checklist were taken for the study. Informed consent was taken from all participants for the study. Ethical clearance was taken for the study from the institutional ethical committee of Kasturba Medical College, Mangalore, Manipal University.

### Stimuli and Physiological Recording
ABRs were elicited by the speech stimulus /da/. Stimulus was obtained from the Auditory Neuroscience Laboratory (Northwestern University, Evanston, IL, USA). A detailed description of the stimuli can be found elsewhere [11, 12]. In brief, the stimulus was composed of five formants that transitioned from consonant /d/ to vowel /a/. The stimuli lasted for 40 ms. The initial 10 ms of the stimuli consisted of onset burst, followed by 30 ms of transition. IHS Smart EP version: 3.92 (Intelligent hearing systems, FL, USA) was used to record and analyze speech-evoked ABR. The stimulus was delivered through Etymotic ER-3 earphones at an intensity of 80 dB SPL. It was presented at 80 dB SPL in alternating polarities at a rate of 7.1/s. ABR recordings were obtained in a darkened double-walled sound-treated booth. The subjects were reclined and relaxed during the recordings. Disc electrodes filled with conductive paste were fixed to skin abraded with a skin prepping gel. Electrode impedances were less than 5 kΩ, and inter-electrode impedances were less than 2 kΩ. To minimize the preferential recording of activity from either side, midline electrode sites were used. The non-inverting electrode was placed on the vertex, and the inverting electrode was placed on the nape of the neck at midline. The ground electrode was placed on the lower forehead. Potentials were band-pass filtered between 30 Hz and 3000 Hz with an amplification factor of 1,00,000. The analysis window was kept at 70 ms (10 ms pre-stimulus and 60 ms post-stimulus). Speech-evoked ABR was first monaurally (left and right) recorded and then binaurally for the /da/ stimulus. Recordings were repeated twice to ensure the replicability of the waveforms.

### Response Analysis
Waveform analysis was performed using mathematical software in the intelligent hearing system. The amplitude of the left ear waveform was digitally added at every sampling point to the amplitude of the right ear waveform to obtain an algebraic sum of the two monaural responses. The binaural difference waveform was then computed by subtracting the binaural waveform from the sum of the two monaural responses. This is expressed as BIC=(R+L)−B, where R+L is the sum of the right- and left-evoked potentials obtained with monaural stimulation, and B is the response acquired from binaural stimulation. Two replications were obtained from each subject. Two expert audiologists were given data to identify BICs in speech-evoked ABR. The average of these replications was used for absolute latencies, and amplitudes for different peaks were analyzed for the summed right and left and binaural wave forms.

## RESULTS
Figure 1 shows the grand averaged speech-evoked ABR for the right and left ears and binaural stimulation along with the waveform of stimulus /da/. The characteristics of the speech-evoked ABR recorded in our study were similar to that reported in literature [10-14]. As can be seen from Figure 1, in all the three waveforms, the temporal features of the signal were well represented. Stimulus onset was evidenced by large positive and negative peaks occurring between 6 ms and 8 ms, which were followed by a series of phase-locked frequency following responses (D, E, F) between 17ms and 47 ms. The presence of an onset response and D, E, and F peaks were highly consistent among all subjects in both the monoaural and binaural recordings. Figure 2 shows the grand averaged speech-evoked ABRs of the summed right and left and binaural waveforms. Figure 3 shows the mean amplitudes along with one standard deviation error bars for peaks V, A, D, E, and F speech-evoked ABR for the summed right and left and binaural waveform. From Figures 2 and 3, it is clear that the amplitudes of both the onset and frequency following components were larger in the right and left summed waveform than in the binaural waveform. A paired-sample t-test showed significantly larger amplitudes in the right and left ear summed waveform than the binaural waveform for peaks V, A, E, and F.

### BIC
Binaural interaction component was calculated by digitally subtracting the amplitude of the binaural waveform from the summed (right plus left) waveform at each data point. Figure 4 shows the grand averaged binaural difference waveform. As can be seen from Figure 4, the binaural difference waveform was highly replicable. In the grand averaged BIC waveform, three major BICs can be identified. The first BIC (BIC-SP1) in the speech-evoked ABR occurred at around 6 ms in the region of peak V. The second BIC (BIC-SP2) was present at around 8 ms in the latency region of peak A. The third and fourth BICs of speech-evoked ABR (BIC-SP3 & BIC-SP4) were observed at around 36 ms and 46 ms, respectively, in the latency regions of peaks E and F, respectively. BIC-SP1 and BIC-SP2 were present in all 15 subjects tested (100% prevalence), whereas BIC-SP3 and BIC-SP4 was present in 11 (73% prevalence). Figure 5 and Figure 6 show the amplitudes and latencies of four different BIC for individual subjects. There was a large degree of individual variations, both in terms of amplitudes and latencies of BICs. Variations were more for later components than for earlier components.

## DISCUSSION
In this study, the binaural difference waveforms were obtained and judged visually for the presence of clear BIC. The results of the pres-
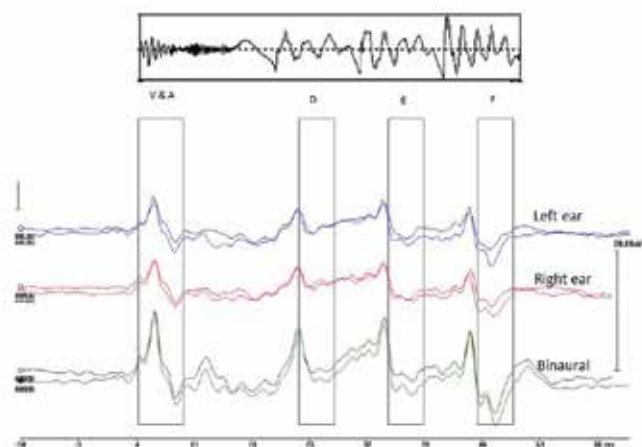
**Figure 1.** Grand averaged speech-evoked auditory brainstem responses for the right and left ears and binaural stimulation along with the waveform of stimulus /da/
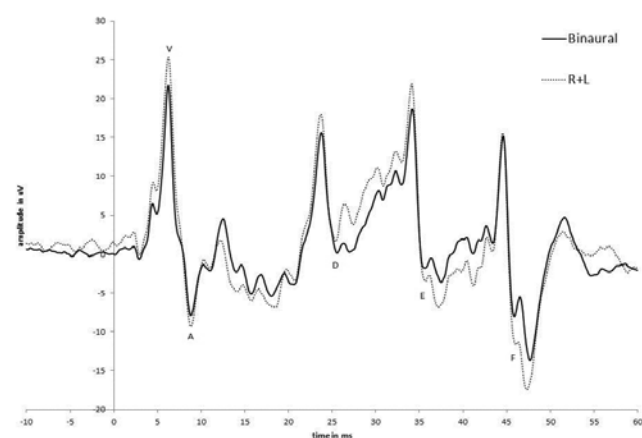


**Figure 3.** Mean amplitudes along with one standard deviation error bars for peaks V, A, D, E, and F speech-evoked auditory brainstem responses for the summed right and left and binaural waveforms



**Figure 2.** Grand averaged speech-evoked auditory brainstem responses of summed right and left and binaural waveforms



**Figure 4.** Grand averaged binaural difference waveform for two recordings

ent study demonstrated that BIC of ABR can be recorded for speech stimuli. We observed that the amplitude of the sum of the monoaural responses was larger than that of the binaural responses. Similar results have been observed for various other stimuli such as clicks, tone bursts, and chirps and for complex signals [7, 12, 15, 16]. This phenomenon can be explained by two mechanisms: (i) binaural stimulation results in reduced firing of contralateral inhibitory and ipsilateral excitatory cells in the superior olivary complex, and (ii) monoaural stimulation drives the contralateral and ipsilateral excitatory cells to saturations and hence will not double the responses to binaural stimulation [17]. In speech-evoked ABRs, stimulus onset is represented by peaks V and A, while the primary periodic features of speech are represented in peaks D, E and F of the frequency following the brainstem response. BICs were observed in both the onset and frequency following portions of the speech-evoked ABRs. The first BIC occurred in the latency region of peak V (BIC-SP1), the second BIC occurred in the latency region of peak A (BIC-SP2), and the third and fourth BICs occurred in the latency regions of peaks E and F (BIC-SP3 and BIC-SP4). Onset BICs were observed in all subjects tested, while frequency following BICs was present in approximately 75% of the subjects tested. These
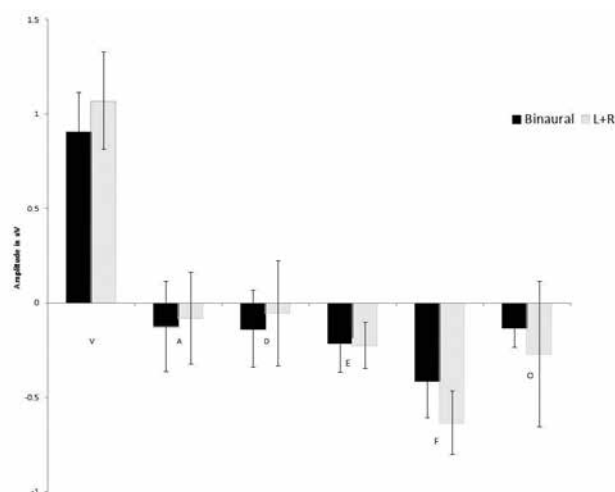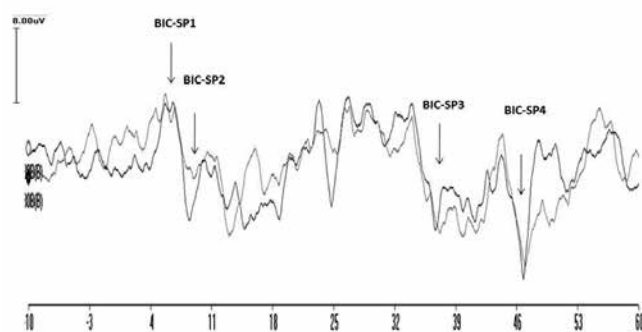
findings show that BIC can be reliable recorded for speech-evoked ABRs in majority of individuals.

Gopal et al. [8] reported that the amplitude of BICs of click-evoked ABR was reduced in children at a risk for developing APD. Gunnarson et al. [18] showed that BIC peaks were present in eight of nine normal children, but in only four of nine children with a recurrent history of persistent and recurrent otitis media. They reported that percentage-visible BIC peaks were the best parameter to distinguish between two groups of children. Delb et al. [9] studied the sensitivity and specificity of BIC of ABR in identifying children with APD on a larger group of subjects. Their results showed a higher error rate of approximately 18% when BIC was used in isolation to distinguish between children with APD and those without. Delb et al. [9] concluded that the latencies and amplitudes of BIC cannot be used as a diagnostic criterion to identify individuals with APDs. King et al. [10] reported that children with learning problems showed no abnormality on click-evoked ABRs but had prolonged latencies for speech-evoked ABRs. They observed that a subgroup of children with learning problems showed delayed onset latencies (peak V and A) to speech stimuli, even though they had normal latencies to click stimuli. All children with learning problems who had delayed onset latencies also showed the prolongation of peaks C and F in FFR. These results indicate that speech may be a more optimal and sensitive stimulus to assess brainstem functioning than
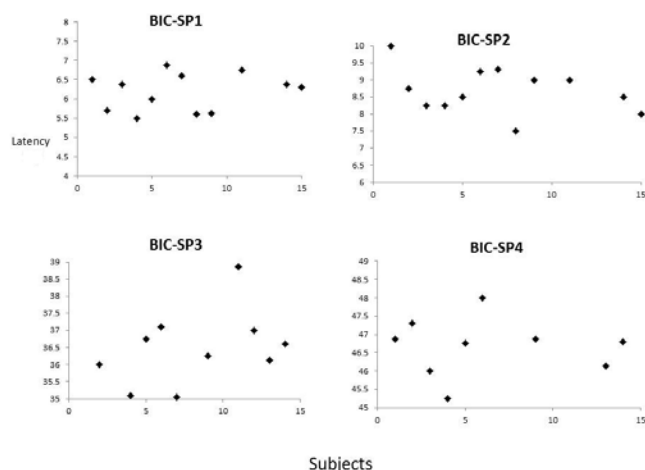
**Figure 5.** Amplitudes of four different binaural interaction components for individual subjects
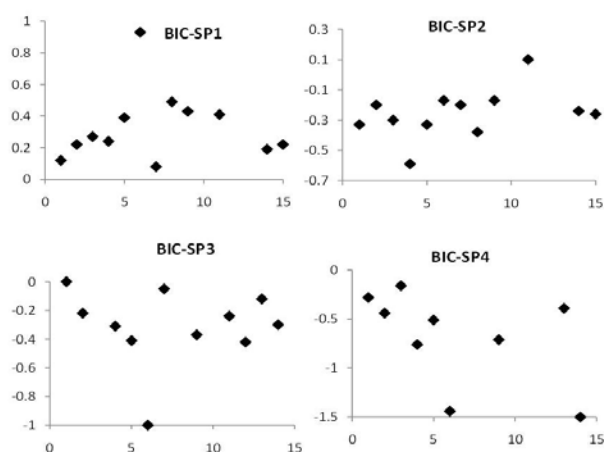


**Figure 6.** Latencies of four different binaural interaction components for individual subjects

click stimuli. In the present study, we demonstrated that BIC can be reliable recorded for speech stimuli. Because ABRs are not affected by sleep and mature early, this tool can be evaluated in identifying binaural interactions in younger and difficult-to-test populations.

In the present study, we demonstrated that BICs can be reliable recorded for speech stimuli. Because ABRs are not affected by sleep and mature early, this tool can be evaluated in identifying binaural interaction in younger and difficult-to-test populations. However, this study has some limitations such as small sample size; hence, these results must be viewed with caution. Further studies with a large sample size are necessary to validate the findings of the current study.

**Ethics Committee Approval:** Ethics committee approval was obtained from Institutional Ethics Committee Kasturba Medical College, Mangalore.

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