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RESEARCH ARTICLE

Test-Retest Reliability of Binaural Interaction Component (BIC) Using Speech and Non-Speech Evoked ABR

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Abstract:

Background and Objective:

Binaural hearing serves as an advantage in daily communication by facilitating better localization of sounds and perception of speech in the presence of noise. BIC of ABR has been used to understand the binaural representation of different stimuli, such as transient clicks, and complex signals, such as speech. The present study aimed to investigate the test-retest reliability of the binaural interaction component for click and speech evoked ABR.

Methods:

30 individuals with normal hearing served as participants for the present study. ABR for click and speech stimuli (/da/) were recorded from these participants in monaural and binaural conditions. BIC was calculated using the formula: BIC = (L + R)- BI where, L + R is the sum of the left and right evoked potentials obtained with monaural stimulation, and BI is the response acquired from binaural stimulation. To investigate reliability, all the participants underwent three recording sessions. Session 1 and session 2 (intra-session) were carried out on the same day, separately. Whereas, session 3 (inter-session) was carried out after a minimum gap of 3 - 5 days after the first session. Intraclass correlation was used to investigate the test-retest reliability of click and speech evoked BIC across the three sessions.

Results:

The test-retest reliability for BIC_{click} was found to be excellent for latency measures and fair to good for amplitude measures. BIC_{speech} was found to be fair to good, except for BIC-3.

Conclusion:

The results of the present study indicate that the reliability of BIC_{click} is better than that of BIC_{speech}. These results suggest that the clinical utility of BIC_{speech} should be exerted with caution.

Keywords: Binaural interaction component, Auditory brainstem response, Binaural Hearing, Speech signals, Interaural time differences (ITD), Binaural interaction component (BIC).

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1. INTRODUCTION

The binaural hearing gives us a substantial advantage in our daily listening situations. Especially, the differences between the ears in terms of intensity [interaural level differences (ILD)] and timing [interaural time differences (ITD)] provide reliable cues regarding the location of the sound sources [1]. The binaural interaction is a phenomenon that helps in the discrimination of speech signals in the presence of background noise. It successively improves the identification and computation at the brainstem level with a minor difference in timing between the signals received at both ears. The Binaural interaction component (BIC) of the auditory brainstem response (ABR) reflects the electrophysiological activity of the binaural neurons central to the cochlear nucleus. It serves as a substrate for the psychoacoustic function of sound localization and lateralization from the superior olivary complex, the nuclei of the lateral lemniscus, and the inferior colliculus [2]. The BIC is an evoked response in normal-hearing individuals, which can be identified in most, but

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interestingly not in all [3 - 5]. BIC of the ABR is an important electrophysiological index of the binaural neural process and is defined as the difference between the sum of the monaural ABRs and the ABR obtained with binaural stimulation [6 - 10].

The ABR obtained for pure tones or the supra-threshold click stimulus is not sensitive towards changes in spectro-temporal characteristics, which are processed in the central auditory system. However, ABRs obtained for speech stimuli are better for the understanding of auditory processing abilities. BICs obtained for speech evoked ABR (BIC_{speech}) provide information on the auditory temporal integration for speech stimuli. BICs have been observed at the region of V, A, C, D, E, F, and O peaks. However, BICs at the region of C, D, and O peaks were inconsistently observed [11]. Ferber, Benichoux, and Tollin12 investigated the test-retest reliability of the DN1 amplitude measure of BIC on guinea pigs. The findings from their study revealed varied responses for the DN1 amplitude measures between and within sessions. Also, reports from the literature [12, 13] suggest highly variable within- and between-subjects BIC waveforms.

The aforementioned studies on test-retest reliability of BIC have predominantly utilized the click stimuli alone, which may be insufficient to provide information about the complex stimulus encoding and neural synchronous firing that occur in natural situations. In such scenarios, speech stimuli are preferred over clicks, as they are complex, unique, and more sensitive towards the binaural integration that occurs at the brainstem. However, there are no studies investigating the reliability of BIC_{speech}, which may help identify lesions or deficits at the level of the brainstem. The current study is an attempt towards addressing this dearth and aims to investigate the reliability of BIC_{speech} and BIC_{click} in individuals with normal hearing.

2. MATERIAL AND METHODS

2.1. Participants

A total of 30 individuals with normal hearing in the age range of 18-25 years (20.75 ± 2.02 years) served as participants for the study. They were selected non-randomly, considering the inclusion and the exclusion criteria. The participants were included based on the criteria that they had normal hearing sensitivity across 250 kHz to 8 kHz, and ‘A’ type tympanogram with the presence of both ipsilateral and contralateral acoustic reflexes. Individuals having any history or presence of neurologic disorders, otologic history, or having conductive or sensorineural hearing loss were excluded from the study.

2.2. Procedure

Click evoked ABR and speech evoked ABR was recorded monaurally (left and right) and then binaurally. The speech evoked ABR was recorded using synthetic speech sound /da/ of 40 ms duration, used by various earlier investigators [14 - 16]. The stimulus was obtained from “Auditory Neuroscience Laboratory,” Northwestern University, Evanston, IL, USA. The click stimuli of 0.1ms duration, which is usually used for conventional ABR evaluation, was used for click-evoked ABR. Click, which is transient stimuli with a broader frequency range, was considered in the study.

IHS Smart EP Evoked potential acquisition system, software version: 5.20 (Intelligent hearing systems, Florida, USA) was used to record ABR and analyze binaural interaction component. Click and speech stimuli were delivered through Etymotic ER-3A earphones at an intensity of 80dBSPL. A total of 2000 click stimuli were averaged using an 11.1 repetition rate with a 15msec analysis time window. Similarly, for speech stimuli, a total of 3000 sweeps were averaged using a 5.1 repetition rate with an analysis time of 70msec. An alternating polarity was used for both stimuli along with a gain of 1 lakh. Filter setting was kept for click stimuli as 100-3000Hz and at 30-3000Hz for speech stimuli. Skin preparation paste was used to clean the electrode sites before placing the electrodes on the individual. To increase the conduction, ten-20 paste was used while placing the electrodes. Recording of ABR was done using both the channel with ipsilateral mode using the conventional electrode montage. The positive electrode was placed on the vertex, the negative electrodes on the mastoid of both the ears, and the common electrode was placed on the forehead. The electrode impedance was maintained to be less than 3Kohm at each electrode and inter-electrode impedance was < 2Kohm

2.3. Test-Retest Reliability

2.3.1. Intra Session Retest Reliability

Click and Speech ABR testing was first carried out monaurally (left and right), and then binaurally (left + right) for the click followed by the /da/ stimulus. All the recordings were repeated twice to ensure the replicability of the waveforms. The click and the speech ABR testing was recorded twice on the same day (session 1 and session 2), separately.

2.3.2. Inter Session Retest Reliability

After a minimum gap of 3-5 days gap following the first day of recording, a third recording session was carried out. Both click and speech ABR testing was repeated as mentioned above to investigate the reliability. The same recording protocol was used across recording sessions.

2.4. Waveform Analysis

2.4.1. BIC Computation

The waveform was analyzed using the inbuilt software of Intelligent Hearing Systems (IHS). The response obtained from the stimulation of the left ear was digitally added to the waveform response obtained from the right ear stimulation. The algebraic aggregate of the two monaural responses was obtained. The added monaural responses were subtracted from the binaural response and the binaural differences were obtained. The concept is expressed as, *Binaural difference waveform* = (L + R)- BI where, L + R is the sum of the left and right evoked potentials obtained with monaural stimulation, and BI is the response acquired from binaural stimulation. Using the same procedure, BIC for click (BIC_{click}) and BIC for speech evoked ABR (BIC_{speech}) were calculated.

Two audiologists independently identified the presence or absence of BIC peaks for click and speech waveforms using the visual identification method. The peaks of BIC_{speech} at the region of V^{th}, A, D, E, F, and O peaks were named as BIC-[1], BIC-2, BIC-3, BIC-4, BIC-5, and BIC-6, respectively. Cohen's kappa coefficient was used to investigate the agreement between the two audiologist's markings of BIC peaks.

2.5. Statistical Analysis

SPSS (version 16) software was used to obtain the mean and standard deviation of the response latencies and the amplitude of BIC. Reliability measures of both the tests were statistically analyzed using intra-class correlation coefficient analysis (ICC). The ICC reliability value of ICC = 1 has perfect reliability, excellent reliability with ICC ≥ 0.75, as good to fair reliability 0.75 < ICC ≥ 0.4 and poor reliability with ICC < 0.4 [17, 18].

3. RESULTS

The binaural interaction is initially observed at the level of the brain; hence, BIC for click stimuli was observed at the V^{th} peak of click-evoked ABR. The occurrence of the BIC_{click} near the V^{th} peak of click ABR was found to be 100%, and it was present in all the participants recruited in this study. The value of kappa coefficient click stimulus was 0.95, which shows almost perfect agreement. The mean latency of BIC was 6.06 ± 0.11 (SD) msec for session 1, 6.08 ± 0.11 (SD) msec for session 2, and 6.11 ± 0.13 (SD) msec for session 3. The ICC value of 0.761 was obtained for the latency of click-evoked BIC. The mean and standard deviation of amplitude measures for session 1, BIC was 0.06 ± 0.05 (SD) µV, 0.08 ± 0.07 (SD) µV for session 2, and 0.07 ± 0.03 (SD) µV for session 3. The ICC value of 0.514 was obtained for amplitude measures of BIC using clicks. The grand average waveform of BIC peaks obtained for click-evoked ABR has been represented across the three sessions in Fig. (**1**).

The occurrences of BIC_{speech} was observed at around 100%, 96.6%, 96.6%, 100%, 100%, and 66% for BIC-1, BIC-2, BIC-3, BIC-4, BIC-5, and BIC-6 peaks, respectively. The value of kappa coefficient speech evoked BIC-1, BIC-2, BIC-3, BIC-4, BIC-5, and BIC-6 were 0.93, 0.91, 0.83, 0.88, 0.87 and 0.85 respectively, which shows strong agreement. The BIC_{speech} obtained at the region of C peak was found to be inconsistent, as the occurrence is found to be 56.6%, which is comparatively less and hence, the BIC at the region of C peak was excluded in the present study. Table **1** represents the mean and standard deviation values for different BIC's observed for speech ABR.

The mean and the standard deviation values for BIC-1, BIC-2, BIC-3, BIC-4, BIC-5, and BIC-6 showed fewer variations across the sessions for latency measures. The ICC value for BIC-1, BIC-2, BIC-4, BIC- 5, and BIC-6 has shown fair to good reliability (0.40 ≥ ICC < 0.75) for latency measures. ICC value for BIC-3 has shown poor reliability for the latency measures. These mean and standard deviation values were found with greater variance across the sessions for amplitude measures of BIC shown in Table **2**.

The ICC values for amplitude measures for BIC-1, BIC-2, and BIC-3 have shown poor reliability and BIC-4, BIC-5, and BIC-6 have shown fair to good reliability. Table **3** represents the ICC value for latencies and amplitude of BIC using speech ABR.

Overall, the latencies measures were more reliable than the amplitude measures for click as well as speech stimuli. The grand average waveform of BIC obtained for speech evoked across the three sessions has been represented in Fig. (**2**).

4. DISCUSSION

In the present study, the BIC_{click} was analyzed at the region of V^{th} peak of ABR. The binaural interaction from both the sides of the ipsilateral pathway begins at the level of the superior olivary complex (SOC) and higher brainstem structures, such as termination of the lateral lemniscus in the inferior colliculus, which is mainly considered as the generator site for the occurrence of V^{th} peak of ABR. Hence, the presence of BIC was usually observed in the region of V^{th} peak, which was more robust when compared to other peaks, such as VI and VII [19]. The BIC-V was present for all the participants recruited in the study with the occurrence rate of 100%, and it was also observed across all the sessions. Similar results have been reported on the presence of numerous peaks for BIC_{click} at the regions of V^{th}, $VI^{th,}$ and VII^{th} peak of click-evoked ABR. These waveforms are termed as DV, DVI, and DVII. But the ABR-BIC occurring in the region of DV (BIC-V^{th} peak) was found to be more reliable and consistently present in normal hearing participants [3, 4, 10].

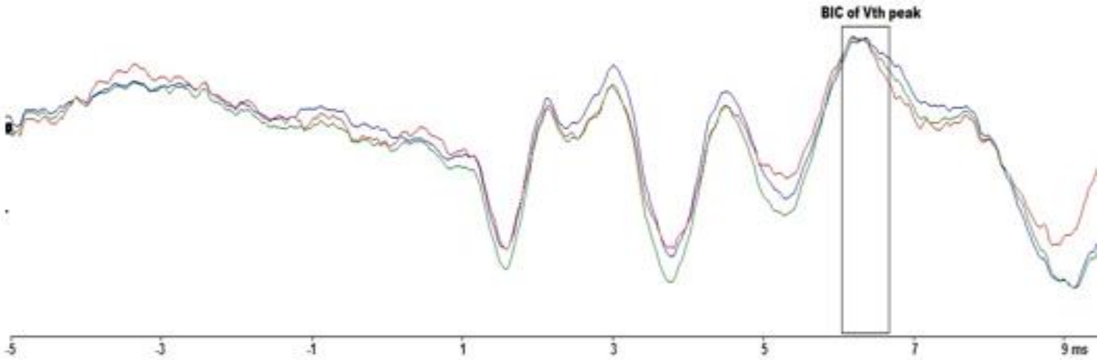

Fig. (1). Grand average waveform of BIC for click-evoked ABR across the three sessions, session 1 (blue), session 2 (red), session 3 (green).

Table 1. - The mean and the standard deviation values across the three sessions (session 1, session 2, session 3) for BIC latencies measures.

BIC for speech ABR	Session 1	Session 2	Session 3
BIC- 1	6.56 ± 0.59 (SD)	6.56 ± 0.66 (SD)	6.6 ± 0.56 (SD)
BIC- 2	8.27 ± 0.75 (SD)	8.43 ± 0.89 (SD)	8.54 ± 0.81 (SD)
BIC- 3	21.52 ± 0.77 (SD)	21.64 ± 0.63 (SD)	21.78 ± 0.68 (SD)
BIC- 4	31.65 ± 0.65 (SD)	31.59 ± 0.75 (SD)	31.9 ± 0.73 (SD)
BIC- 5	41.02 ± 0.98 (SD)	40.7 ± 1.08 (SD)	40.65 ± 0.94 (SD)
BIC-6	48.25 ± 0.79 (SD)	48.06 ± 0.59 (SD)	48.18 ± 0.73 (SD)

Table 2. The mean and standard deviation values for the amplitude measures for different BIC values obtained using speech evoked ABR.

BIC for speech ABR	Session 1	Session 2	Session 3
BIC- 1	0.08 ± 0.1(SD)	0.07 ± 0.5 (SD)	0.09 ± 0.1(SD)
BIC- 2	-0.09 ± 0.12 (SD)	-0.08 ± 0.1 (SD)	-0.09 ± 0.1(SD)
BIC- 3	-0.18 ± 0.21 (SD)	-0.09 ± 0.2 (SD)	-0.12 ± 0.18 (SD)
BIC- 4	-0.1 ± 0.07 (SD)	-0.07 ± 0.09 (SD)	-0.1 ± 0.13 (SD)
BIC- 5	-0.09± 0.17 (SD)	-0.05 ± 0.14 (SD)	-0.05± 0.14 (SD)
BIC-6	-0.12 ± 0.1 (SD)	-0.09 ± 0.11 (SD)	-0.13 ± 0.11 (SD)

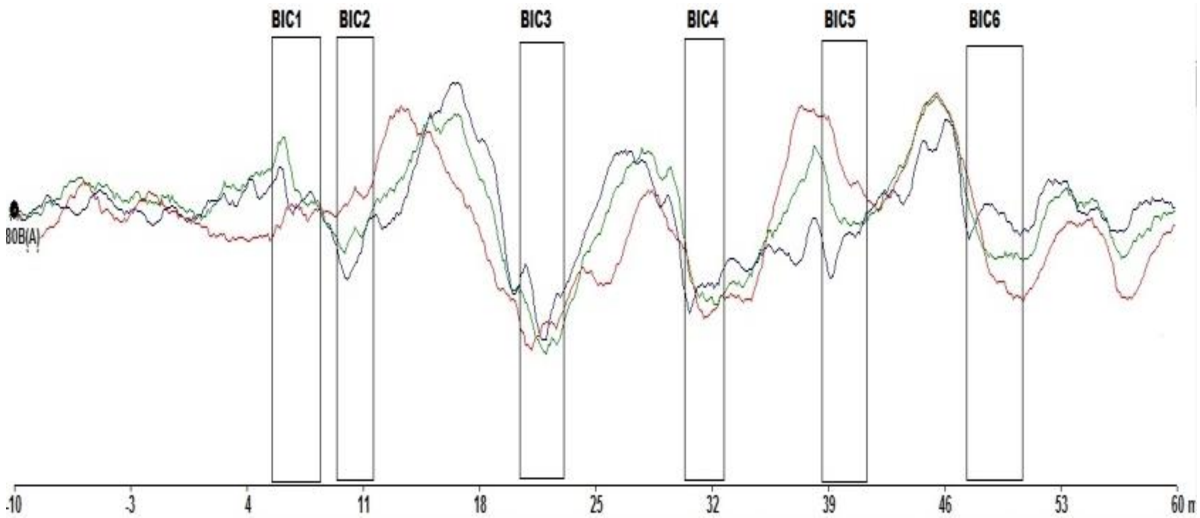

Fig. (2). The grand average waveform of BIC for speech evoked ABR across the three sessions, session 1 (blue), session 2 (red), session 3 (green).

Table 3. Represents the intraclass correlation (ICC) values for BIC-1, BIC-2, BIC-3, BIC-4, BIC-5, and BIC-6 for latency and amplitude measures in speech evoked ABR.

BIC for speech ABR	Latency	Amplitude
BIC- 1	0.637	0.389
BIC- 2	0.518	0.360
BIC- 3	0.293	0.303
BIC- 4	0.528	0.408
BIC- 5	0.513	0.539
BIC-6	0.464	0.469

Reliability of BIC-Vth peak was found to be excellent for latency measures and fair to good for amplitude measures in click-evoked ABR in the present study. A study has been reported with an excellent inter-observer agreement, which has confirmed the reliability reported for DV for both the latency and amplitude measures [9]. A similar study has been conducted in guinea pigs for the amplitude of binaural interaction components using the click-evoked ABR, and the results have shown greater variations across sessions. These amplitude variations could be due to the varied measurement parameters such as the electrode placement, electrode location, electrode depth, which affects the ABR waveform monaural and binaural recordings. It may also be due to the effects of the signal-to-noise ratio (SNR) and, in turn, BIC peak amplitude[12]. Studies on click-evoked ABR on normal hearing individuals have reported fewer variability in terms of latencies and greater variability for amplitude in ABR waveforms. These variations are attributed to the equipment and techniques used during recording [20, 21]. In the present study, it was also observed that the BIC_{click} showed lesser variability for the latency measures and greater variability for the amplitude measures.

In the present study, the occurrence rates for BIC_{speech}, especially, BIC-1, BIC-2, BIC-3, BIC-4, BIC-5, and BIC-6 were 100%, 96.6%, 96.6%, 100%, 100%, and 66%, respectively. Similar BIC results were obtained in which the occurrences of onset responses, *i.e.*, Vth peak (BIC-1) with large positivity and A peak (BIC-2) with large negativity with 100% prevalence, have been observed using speech evoked ABR [11]. The authors also report that the frequency following responses (FFR) was found to be around 73% prevalent at the latency region of E (BIC-4) and F (BIC-5) peaks. Another study[16] reports an occurrence of 100% for the onset and 82.3% for the offset of FFR with alternating polarity for speech evoked ABR. The occurrence of O response varied with polarities, the highest occurrences (94%) was observed for rarefaction polarity. In the present study, alternating polarity was used, which could be the reason for the poor occurrences for offset response. These differences in the occurrence of the offset responses in speech evoked ABR could be due to the electrode placement and the technical parameters considered during the recording. Reliability measures have shown fair to good reliability for BIC-1, BIC-2, BIC-4, BIC- 5, and BIC-6. Reliability for BIC-3 was found to be poor for latency measures. The amplitude measures for BIC-1, BIC-2, and BIC-3 has shown poor reliability. BIC-4, BIC-5, and BIC-6 have shown fair to good reliability. Similar findings have been reported by other studies [22], in which reliability for the speech evoked ABR latency ranged from 0.12 to 0.56 in quiet situations across the two sessions separated by a one-year interval. Reliability measures were reported to be poor for the onset response latency compared to FFRs, and the offset responses in children. In addition to this, the authors also report a highly replicable spectral encoding and signal to noise ratio. In the present study, poor reliability for amplitude measures was found for BIC. A study by Russo *et al*. [15], also reports significant variation in the inter-peak amplitude for the Vth and A peaks, which is similar to the findings of the present study. Song *et al*. [23], have reported no significant differences for speech evoked ABR peaks in normal hearing individuals for both latency and amplitude measures across two sessions.

CONCLUSION

It can be summarized from the present research that the occurrences of BIC for click and speech evoked ABR was greater than 90% except for O peak in speech evoked ABR. The reliability of latency of BIC_{speech} varied from 0.29 to 0.62, and for amplitude, it was 0.30 to 0.53. The reliability of BIC_{click} latency was 0.76 and 0.51 for amplitude. The lower reliability for amplitude might be due to the differences in measurement parameters, such as the electrode placement, electrode location, and inter-electrode impedance. These parameters may have affected the waveforms of monaural and binaural ABR recordings, and hence, affect the SNR. These findings emphasize a need for careful consideration of BIC_{speech} for clinical diagnosis.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study has been approved by the ethical Committee of Kasturba Medical College Mangalore, India with approval number IEC KMC MLR 11-15/269.

HUMAN AND ANIMAL RIGHTS

No animals were used in this research. All human research procedures were followed in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national), and with the Helsinki Declaration of 1975, as revised in 2013.

CONSENT FOR PUBLICATION

Written consent was obtained from all participants of the present study after having been informed of the nature of the study they would take part in.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

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