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The Presence of Binaural Interaction Component (BIC) in the  
Auditory Brainstem Response (ABR) of Normal Hearing Adults

By

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A Professional Research Project submitted to the Faculty of the  
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(ABSTRACT)

The purpose of this study was to determine the prevalence of the binaural interaction component (BIC) in a large sample of normal hearing adults, and to measure the absolute latency and amplitude of the BIC as a function of the click rate of the stimulus and the electrode montage. The BIC is obtained by subtracting the auditory evoked potential waveform obtained with binaural stimulation from the waveform obtained by adding the responses from the left and right monaural stimulation. The tested hypothesis was that the recordings of the BIC vary among normal hearing individuals, and BIC latency and amplitude values change as a function of stimulus rate. Studies of the BIC help to explain the neural correlates of some binaural processes, and to develop an electrophysiological index of binaural processes for objective clinical evaluations.

Data was completed and analyzed on 47 adults between the ages of 20 and 41 (mean = 25) with hearing in the normal range (thresholds  $\leq 20$  dB HL at 500, 1000, 2000, and 4000 Hz in each ear) and no known neurological disorders. The results revealed a great variability in BIC morphology between subjects. The BIC waveforms were categorized into five distinct groups according to the number of positive and negative peaks present. Chi-square analyses revealed a significant relationship between click rate and BIC category; however, the relationship between recording montage and BIC category was insignificant. An Analysis of Variance (ANOVAs) revealed a significant increase in absolute latency and decrease in absolute amplitude of both negative and positive peaks as click rate increased from 7.7/s to 57.7/s. The results did not reveal a significant change in the type of BIC as an effect of electrode montage.

In conclusion, the BIC within the binaural difference waveform may be obtained in the majority of young individuals with normal hearing. Specifically, a slower stimulus rate revealed more components of the waveform, as well as an improvement in the morphology of the BIC compared to a faster stimulus rate. As these findings may aid in

the development of an electrophysiological index of binaural neural processes in young individuals with normal hearing, more research should be attempted in the study of BIC in other age groups and patients with different audiograms.

## Introduction

Binaural processing is evaluated clinically by means of behavior assessment of skills such as, auditory localization and detection in noise (the masking level difference test). Currently, there is an attempt by researchers to use the measurement of the binaural interaction component (BIC) of the auditory brainstem response (ABR) to record the function of binaural neural processes. The development of such a physiological measurement is essential to provide objective information in many populations, including infants and other difficult to test patients. To understand the impetus of this investigation, the principles and applications of ABR will be reviewed with a focus on the presence of BIC in the ABR.

ABR is a powerful diagnostic tool that provides both valuable neurological and audiological information. Hood (1998) discussed the main clinical applications of ABR which consist of the identification of neurological abnormalities in the VIII<sup>th</sup> nerve and auditory pathways of the brainstem, and the estimation of hearing sensitivity. The ABR is a transient potential that is a far-field scalp recording produced by brief acoustic signals such as clicks or tone bursts (Hood, 1998; Jewett, 1970; Jewett & Williston, 1971). The ABR is a measure of neural synchrony of the time-locked, onset-sensitive, single-unit activity in the auditory nerve and the brainstem (Hood & Berlin, 1986). Stimuli with a very rapid onset are used to elicit synchronous discharge of a large number of neurons occurring during the first 10 msec after the presentation of the stimulus (Møller, 1998). Roman numerals I through VII are used to label the ABR wave peaks, and Roman numerals with a prime (') symbol are used to identify the negative troughs following each positive peak (Jewett & Williston, 1971).

The neural generators of the ABR waveforms have been studied in humans by measuring directly from the VIII<sup>th</sup> nerve with intracranial electrodes. These responses were recorded in patients who have known focal brainstem lesions while undergoing neurosurgical operations. Møller, Jannetta, and Sekhar (1988) examined the contributions of the auditory nerve to the ABR. These investigations compared intraoperative recordings obtained from electrodes placed on the scalp with recordings made directly from the VIII<sup>th</sup> nerve in patients undergoing microvascular decompression

(MVD) operations to relieve hemifacial spasm (HFS) and disabling positional vertigo. The latency values of the ABR wave I were similar to that of the negative peak of the compound action potential (CAP) generated by the distal portion of the VIII<sup>th</sup> nerve. In addition, the latencies of wave II of the ABR were similar to the initial negative peak in the CAP when recorded from the proximal portion on the intracranial portion of the VIII<sup>th</sup> nerve. This study concluded that the auditory nerve is the generator of both waves I and II of the ABR. Further, these investigators suggested that wave III of the ABR is the earliest potential generated within the brainstem as they demonstrated that wave III of the ABR has a latency value that was similar to the potentials generated within the cochlear nucleus. These data confirmed an earlier investigation completed by Møller and Jannetta (1981), which suggested the neural generator of the wave III in the ABR to be the cochlear nucleus. The implication of the auditory nerve, brainstem and subcortical structures as the generators of the ABR were further examined by Hashimoto, Ishiyama, Yoshimoto, and Nemoto (1981). These researchers recorded intracranial evoked potentials directly from the VIII<sup>th</sup> nerve, brainstem, thalamus, cerebellar and cerebral cortices to delineate the generating sources of each ABR component recorded through the scalp. The results of this study coincided with the findings that wave I is generated within the distal portion and wave II in the proximal portion of the VIII<sup>th</sup> nerve. In addition, their results showed that the third positive component of the auditory-evoked potentials, recorded from the midpons level, started and ended in time with wave III of the ABR. The fourth positive component of the pontine potentials corresponded to wave IV of the ABR and suggesting that the neural generator of wave IV is from the pons whereas, the intracranial evoked potential corresponding to wave V is maximal at the midbrain. Subsequently, Møller and Jannetta (1982) recorded intracranial evoked potentials from the inferior colliculus in human and confirmed that wave V of the ABR was generated by the lateral lemniscus, where it terminates in the contralateral inferior colliculus.

#### Description of Binaural Interaction Component (BIC)

Jewett (1970) first suggested the BIC in cats occurring at the time of waves IV and V, by showing that the ABR evoked by binaural stimuli differed from the sum of the monaurally evoked responses. The BIC has been successfully demonstrated in guinea

pigs (Dobie & Berlin, 1979; Gardi & Berlin, 1981; Huang, 1980), dogs (Huang, 1980) and humans (Ainslie & Boston, 1980; Dobie & Norton, 1980; Levine, 1981; Wrege & Starr, 1981). Wada and Starr (1989) found that the BIC in humans occurs at the same time as waves V and VI in cats. The results of these studies agreed that BIC is generated by the auditory nuclei in the brainstem at the level of third order neurons that synapse with the superior olivary complex (Dobie & Berlin, 1979). Within the brainstem, possible structures involved in generating the BIC are: the inferior colliculus (Lehman & Hafter, 1972), the dorsal nucleus of the lateral lemniscus (Brugge, Anderson, & Aitken, 1970), dorsal cochlear nucleus (Mast, 1970), and the superior olivary complex (Hall, 1965).

Researchers have shown that summation of monaural ABRs do not predict the ABRs obtained with binaural stimulation (Brantberg, Fransson, Hansson, & Rosenhall, 1999; Levine, 1981; Gardi & Berlin, 1981; Wrege & Starr, 1981; Dobie & Norton, 1980; Jewett, 1970). The BIC is derived by subtracting the ABR obtained with binaural stimulation from the waveform obtained by adding the responses from the left and right monaural stimulation. This 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. The BIC is most apparent in the binaural difference waveform obtained in humans at 4.5 to 7.0 ms after the stimulus onset, which is coincident with waves IV to VI (Wrege & Starr 1981).

#### BIC Measurement and Clinical Significance

In previous studies, researchers have investigated the anatomical and electrophysiological mechanisms that produce the BIC. The studies of the BIC serve the purpose of explaining the neural correlates some binaural psychoacoustical processes, such as sound localization, binaural loudness summation, and binaural release of masking (Brantberg et al., 1999). Researchers studying the BIC attempted to describe the electrophysiological activity that is underlying these binaural psychoacoustical processes. For instance, Wrege and Starr (1981), and Dobie and Berlin (1979) have studied these effects using time and/or intensity differences as the stimuli presented to their subjects' ears. Wrege and Starr (1981) showed that the amplitude of the BIC attenuated when

click intensity was reduced from 70 to 60 dB SL. The attenuation of BIC was greater than the attenuation of the sum of the monaurally evoked potentials. In addition, the latency of the BIC increased as the interaural time difference increased from 0 to 500 msec. The latency shift and the amount of interaural delay were proportionally related. Thus, BIC is affected by stimulus intensity and interaural time difference and is clearly affected by binaural neural processing.

Dobie and Norton (1980) suggested that the BIC has potential for clinical evaluation of patients with suspected disorders of the central auditory nervous system or damage to the central auditory pathways. Further investigations conducted by Gopal and Pierel (1999) have shown the BIC to be reduced in amplitude in subjects who are diagnosed with an auditory processing disorder (APD). These authors concluded that with better characterization, the BIC may reflect auditory processing capabilities and be used as an index of binaural processing (Gopal & Pierel, 1999).

#### BIC Controversies

Although the BIC has been successfully recorded in animals and humans in some studies, there are also reports of failure to record BICs. Stollman, Snik, Hombergen, Nieuwenhuy and Koppel (1996) reported variability in the morphology of BIC, even among normal hearing subjects. Gerken, Moushegian, Stillman, and Rupert (1975) used the same paradigm employed by Dobie and Berlin (1979) to compare the summed monaurally to binaurally evoked responses of BIC. They found no significant differences between the two measurements; thus, BICs were not recorded. However, most of the studies of BIC were based on a small number of subjects. Thus the results and conclusions might not represent the majority of the population.

To explain the variability of BIC measurements in human subjects, some researchers have looked at factors related to age. In a study conducted by Kelly-Ballweber and Dobie (1984), subjects were divided into two groups. The mean age of the younger subjects was 39.1 years, and the mean age of the older subjects was 69.4 years. The results of their study showed that the older subjects presented increased wave V latencies of the ABR in both the monaural and binaural responses. Jerger and Hall (1980) studied the effects of age and gender on the ABR and showed an effect of aging on the latency and amplitude of wave V. Latency increased and amplitude decreased



over the age range from 25 to 55 years. In addition to age, Jerger and Hall (1980) showed a gender effect. Female subjects in both normal and hearing-impaired groups showed consistently shorter latency and larger amplitude at all age levels as compared to the male subjects. Since age and gender influence the ABR waveforms, BIC responses also likely vary as a function of these two factors.

#### Stimulus Rate

Thornton and Coleman (1975) studied the adaptation of cochlear and brainstem auditory evoked potentials in humans. They discovered that the wave V latency increases and wave V amplitude decreases as a function of increased click rate. The amount of adaptation increases with increasing click rate. Don, Allen, and Starr (1977) showed that the latency shift of wave V was approximately 0.5 msec as the click rate was increased from 10/sec to 100/sec. Shipley, Strecker, and Buchwald (1984) demonstrated that an increase in stimulus rate from 10 to 100 clicks per second reduced the BIC markedly in cats. A decrease in BIC amplitude as an effect of increased stimulus rate has also been shown in human studies (Fullerton, Levine, Hosford-Dunn, & Kiang, 1987; Levine, 1981). The implications of the results of these studies suggest that the BIC is also affected by the stimulus rate.

#### Purpose

The purpose of this study was to determine the prevalence of the BIC in a large sample of normal hearing adults ( $N = 50$ ), and to investigate the change in the BIC latency and amplitude values by manipulating the stimulus click rate and the electrode montage. According to Shipley, Strecker, and Buchwald (1984), identifying systematic changes in the BIC with varying stimulus parameters is useful for: (1) characterizing the activity of ABR generator systems more exactly and facilitating the identification of these generators; (2) evaluating models of physiological processes underlying the mechanism of BIC; and (3) establishing optimum stimulation procedures.

## Methods

### Subjects

The study group included 42 females and 8 males between the ages of 20 to 41 (mean = 25) with no known neurological disorders. All subjects in this study passed a hearing screening with thresholds  $\leq 20$  dB HL at 500, 1000, 2000, and 4000 Hz in each ear (American National Standard Institute, 1996; American Speech-Language and Hearing Association, 1995). In addition, the subjects had normal tympanograms and present ipsilateral acoustic reflexes at 500, 1000, and 2000 Hz, and contralateral acoustic reflexes at 1000 and 2000 Hz in both ears. A calibrated immittance system (GSI-28) according to ANSI S3.6 was used for the immittance testing.

### Stimuli

All ABR testing was completed using a Nicolet Spirit 4-channel evoked potential system. Stimuli were 100 msec condensation or rarefaction clicks presented at 75 dB nHL via ER-3A insert earphones. Each stimulus condition consisted of 1500 click presentations. Two stimulation sequences were obtained and averaged for each stimulus condition. Stimulus rates were employed at 7.7/s and 57.7/s. Left and right monaural stimulation sequences were first recorded, followed by binaural stimulation sequences. Therefore, each of the 50 subjects was tested under 6 different stimulus conditions. Each participant was examined in one session of approximately 60 minutes.

### Recordings

ABR recordings were obtained in a darkened double-walled sound treated booth (IAC, Inc). Subjects were reclined and relaxed during the recordings. Disc electrodes filled with conductive paste were fixed to skin abraded with skin prepping gel (Nuprep). In order 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 on the nape of the neck at midline. The ground electrode was placed on the forehead. Electrode impedance was kept below 2000 ohms for all electrodes, and within 1000 ohms between all electrode pairs. The responses were amplified and bandpass filtered from 100 to 3000 Hz. Responses were averaged over a 14 msec interval (4 msec prestimulus and 10 msec post stimulus) at a sampling rate of 37.04 kHz. The ipsilateral,

midline, and standard recording montages were used for the recording of data. Table 1 illustrates the derivatives of the binaural difference waveforms using the three different electrode montages. The waveform measured between the vertex and the ear being stimulated constitutes the ipsilateral recording, whereas the waveform measured between the vertex and the ear opposite of the ear being stimulated constitutes the contralateral recording. In the midline recording montage, the recording is obtained between the vertex and the nape of the neck, in which the montage parallels the brainstem.

Table 1

The Formulae Used to Derive the BIC in the Ipsilateral, Midline, and Standard Recording Methods.

<b>Recording Montage</b>	<b>BIC Computation</b>
Ipsilateral	$BIC = (R \text{ Ipsilateral} + L \text{ Ipsilateral}) - (BI \text{ Ipsilateral} + BI \text{ Contralateral})$
Midline	$BIC = (R \text{ Midline} + L \text{ Midline}) - BI \text{ Midline}$
Standard	$BIC = (R \text{ Ipsilateral} + R \text{ Contralateral}) + (L \text{ Ipsilateral} + L \text{ Contralateral}) - (BI \text{ Ipsilateral} + BI \text{ Contralateral})$

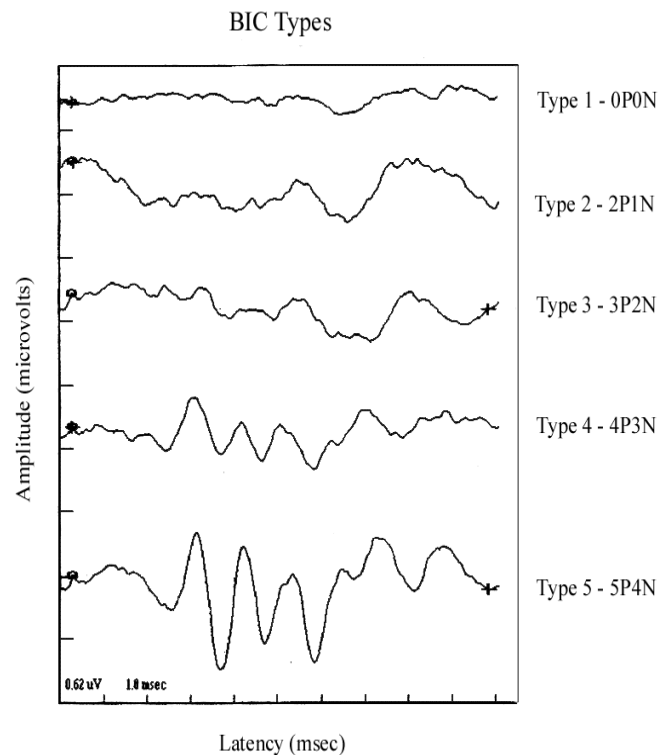
Analysis of Recordings

Waveform analysis was performed using mathematical software in the Nicolet Spirit. The waveform from the left ear stimulation was digitally added to the waveform from the right ear stimulation to form the algebraic aggregate of the two monaural responses. The binaural difference waveform was then computed by subtracting the binaural waveform from the aggregate of the two monaural responses. This 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.

Data Analysis

Statistical analyses were performed using both non-parametric and parametric techniques. In the non-parametric study, the BICs were categorized into the five different groupings according to the number of positive and negative peaks present. The

categories are as follows: type 1 consists of no positive peak and no negative peak, type 2 consists of two positive peaks and one negative peak, type 3 consists of three positive peaks and two negative peaks, type 4 consists of four positive peaks and three negative peaks, and type 5 consists of five positive peaks and four negative peaks. Figure 1 illustrates examples of the five BIC types.



**Figure 1.** Examples of the five BIC types.

The distribution of BIC types was analyzed as an effect of click rate (i.e., 7.7/s and 57.7/s) and recording montage (i.e., ipsilateral, midline, and standard) using the chi-square analysis.

Positive and negative peaks were then identified and marked in the post stimulus period of the binaural difference waveform. The positive peaks were labeled as  $P_1$ ,  $P_2$ ,  $P_3$ ,  $P_4$ , and  $P_5$ , and the negative peaks were labeled as  $N_1$ ,  $N_2$ ,  $N_3$ , and  $N_4$  accordingly. The dependent variables of this study were the absolute latencies and amplitudes of these positive and negative peaks. The latencies of the peaks were measured in msec, and the amplitudes were measured in microvolt.

## Results

Non-Parametric Analysis

Fifty subjects were tested, however, the data of three subjects were discarded due to an excessive amount of artifact in the recordings. The results revealed a great variability in the morphology of the BIC among these normal hearing subjects. Thus, a categorization system was developed to organize the BIC waveform morphologies. Each binaural difference waveform was categorized into one of the five types as described earlier, according to the number of positive and negative peaks present in the waveform.

Figure 2 illustrates the distribution of BIC types collapsed across recording montage and click rate. The chi-square ( $\chi^2$ ) analysis indicated a significant difference [ $\chi^2(4)=162.93$ ;  $p<0.0001$ ] in the distribution of BIC types. However, two predominant types (types 3 and 4), represented 29.78% and 42.91%, respectively, of all recordings. The other types were less common, represented by 2.13% for type1, 19.86% for type 2, and 5.32% for type 5. Subjecting these data to a Proportions Tests (see Table 2) demonstrated that BIC type 4 had significantly greater incidence than types 1, 2 and 5, but not significantly greater than BIC type 3. Further, BIC type 3 had significantly greater incidence than BIC type5, but not types 1, 2 and 4.

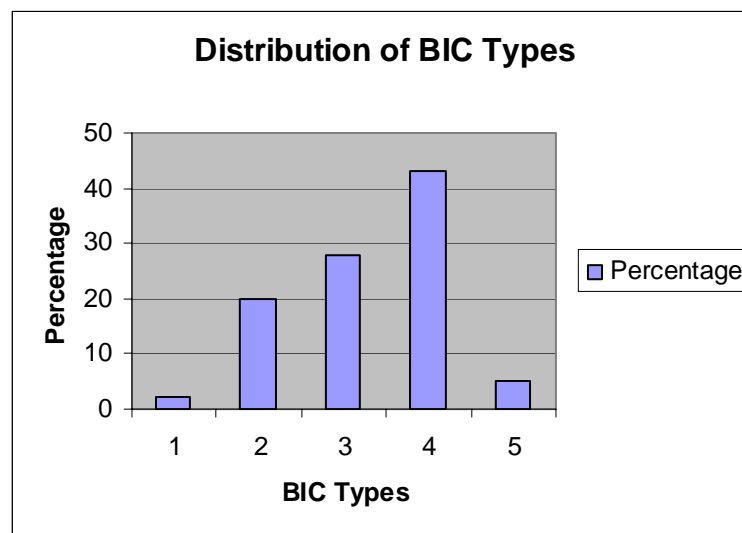


Figure 2. Distribution of the BIC types.

Table 2

The Results of the Proportions Test Analysis.

<b>BIC Types</b>	<b>z Value</b>	<b>p Level</b>
1 vs. 2	1.34	>0.05
1 vs. 3	1.81	>0.05
1 vs. 4	2.35	<0.05
1 vs. 5	0.28	>0.05
2 vs. 3	1.34	>0.05
2 vs. 4	3.08	<0.01
2 vs. 5	1.54	>0.05
3 vs. 4	0.54	>0.05
3 vs. 5	2.32	<0.05
4 vs. 5	3.25	<0.01

Significance at the 0.05 level requires a z value >1.96 and at the 0.01 level a z value >2.58.

Figure 3 shows the distribution of the BIC types as an effect of recording montage with the click rate collapsed. Each of the recording method produced all five types of BICs, and there was no significant change [ $\chi^2(8)=2.96$ ;  $p>0.094$ ] in the BIC types as an effect of recording montage.

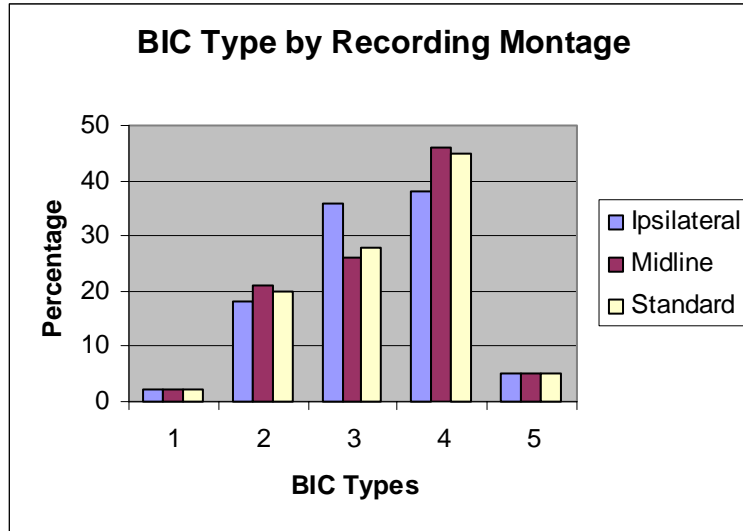


Figure 3. BIC type by recording montage

Figure 4 demonstrates the change of BIC type as an effect of click rate with the various recording montages combined. In general, there is a significant change [ $\chi^2(4)=90.16$ ;  $p<0.0001$ ] in type associated with click rate. The largest rate effect occurred in types 2 and 4. As the click rate increased from 7.7/s to 57.7/s, the prevalence of type 2 increased from 0% to 39.72% and type 4 decreased from 61.70% to 24.11%.

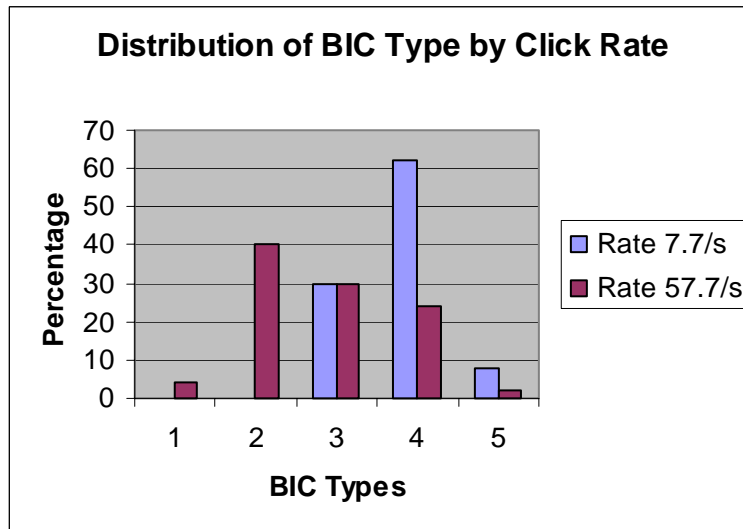


Figure 4. Distribution of BIC type by click rate.

Parametric Analysis

An Analysis of Variance (ANOVA) with two within-subjects factors (click rate and BIC recording montage) was used to determine the effect of click rate on BIC latency and amplitude. The analysis revealed that absolute latencies and amplitudes of the same

peak did not differ significantly as a function of electrode montage (i.e., ipsilateral, midline, and standard), therefore, further analyses included only the data obtained with the midline method. Subjects 4 and 7 were eliminated from the analysis, as they did not have a BIC in the binaural difference waveform. Their BIC responses were essentially flat waveforms, with no positive or negative peaks.

Theoretically, the BIC is found between the latencies of wave IV and VI of the ABR, and a distinct negative peak followed by a positive peak characterizes it. In this study, the negative peak was labeled as  $N_a$ , and the positive peak was labeled as  $P_a$ . The amplitude between  $N_a$  and  $P_a$  was termed  $A^a$ . In all cases, the alpha significance level was 0.05.

Figure 5 shows the mean values of  $N_a$  and  $P_a$  at the two stimulus rates. The mean latency of  $N_a$  was 5.06 msec at 7.7/s and 5.63 msec at 57.7/s, and the mean latency of  $P_a$  was 6.13 msec at 7.7/s and 6.86 msec at 57.7/s. ANOVA results revealed a significant effect of click rate [ $F(1,44)=76.46$ ;  $p<0.000001$ ] on the latency values. The mean measurement of  $A^a$  was 0.75  $\mu$ volts at 7.7/s and 0.58  $\mu$ volts at 57.7/s as shown in Figure 6. There was also a significant effect of click rate [ $F(1,44)=11.46$ ;  $p=0.0015$ ] on the amplitude values. Tukey post-hoc analyses revealed that the latencies of  $P_a$  and  $N_a$  were significantly longer, and the amplitude ( $A^a$ ) was significantly smaller for the fast click rate than for the slow click rate ( $p<0.05$ ).



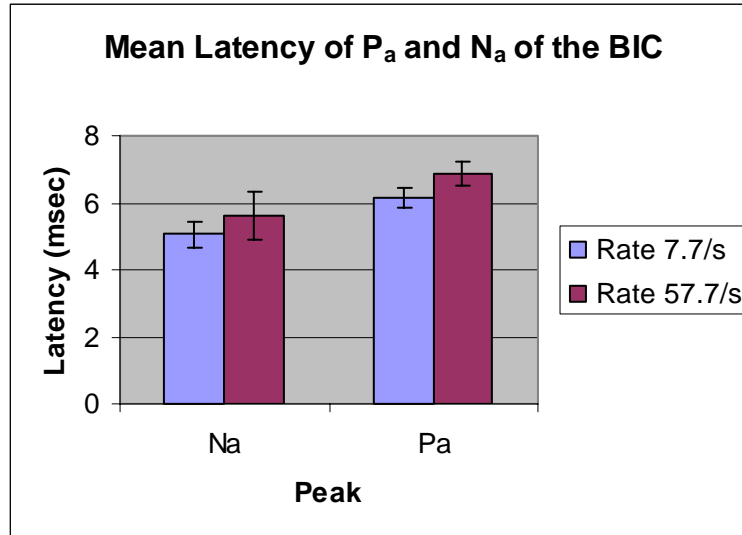


Figure 5. The mean latency values for both the positive ( $P_a$ ) and negative ( $N_a$ ) peaks of the BIC.

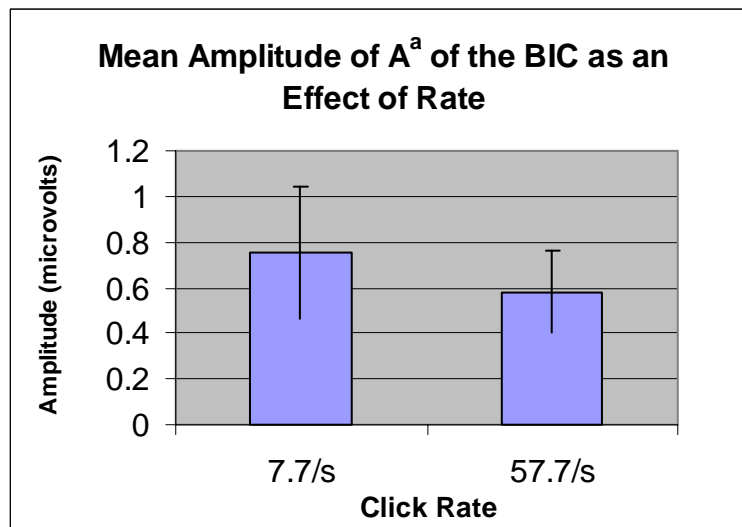


Figure 6. The effect of click rate on the value of the mean amplitude ( $A^a$ ).

### Discussion

Though it has been suggested that the BIC might serve as an electrophysiological index of binaural neural processes, a clinical application using this measurement has not yet been established. This lack of development may very likely be due to the contradicting results obtained in former studies. While some studies confirmed the

presence of BIC (Brantbert et al., 1999; Dobie & Berlin, 1979; Dobie & Norton, 1980; Gopal & Pierel, 1999; Wrege & Starr, 1981); others question its existence and reliability (Gerken et al., 1975; Stollman et al., 1996). As these previous studies were completed using a small number of subjects, the current study was developed to investigate the prevalence of the BIC in a large sample of normal hearing adults. This study further investigated the change in the latency and amplitude measurements of BIC by manipulating the click rate of the stimulus and the electrode montage. However, the effect of age and gender was not a focus in this study. The subjects used were young adults between the ages of 20 and 41, and the majority of them were females.

The binaural difference waveforms were obtained and judged visually for the presence of a obvious BIC. In this study, BICs from 50 subjects with normal hearing were recorded. The results indicated a great variability in the binaural difference waveform morphology among these subjects, which is supportive of Stollman et al. (1996). As there were different binaural difference waveform morphological patterns, a categorization system was developed to group these waveforms into five types. The categorization was based on the number of positive and negative peaks that comprises these waveforms. Figure 1 shows examples of the five types of binaural difference waveforms from five different subjects. Dobie and Norton (1980) suggested several explanations of why the human BIC response showed considerably more variability than that of the guinea pig. First, because of the anatomical differences in brain and skull, ABR amplitudes of the guinea pig are usually measured in microvolts as compared to the sub-microvolt levels seen in humans. Secondly, guinea pigs exhibit a higher signal-to-noise ratio that leads to a more distinguishable response even when fewer samples are averaged. Lastly, the stability of the guinea pig ABR recordings is enhanced by the anesthesia used.

It is apparent that there is individual variation in BIC morphology. Yet, each of the BICs may be categorized into one of the five types depending on the number of positive and negative peaks. Given the variability in the morphology of the binaural difference waveforms, the chi-square analysis confirmed that two BIC patterns, type 3 and type 4, showed significant predominance. Of all the recordings collected, with the recording montage and click rate collapsed, 80% were either a type 3 or a type 4. The

type 3 waveform has three positive and two negative peaks, and the type 4 waveform has four positive and three negative peaks. Both of these binaural difference waveform types reveal a visible morphology of the majority of the waves. Thus, it may be concluded that relatively good morphology of binaural difference waveforms is obtainable in most people.

The results of this study did not reveal a significant change in the type of BIC as an effect of electrode montage. Theoretically, the midline recording method is a vertical montage paralleling the brainstem. This montage should help to emphasize wave V of the ABR where the BIC occurs. However, preliminary data analysis revealed no significant difference in the latency and amplitude measurement by using the midline method versus the ipsilateral and the standard recording methods. These results suggest that the measurement of BIC is equally obtainable by either the ipsilateral, midline, or standard recording montages.

Contrarily, there is a click rate effect on the type of BIC with the various recording montages combined. The most pronounced rate effect occurred in types 2 and 4. As the rate changed from 7.7/s to 57.7/s, the number of BIC type 2 waveforms increased and the number of type 4 waveforms decreased significantly. In addition, type 1 was recorded in two of the 47 subjects at the faster rate only. This type consists of no positive or negative peak, which is essentially a relatively flat waveform. Specifically, the slower click rate produced more distinct waveforms with more apparent positive and negative peaks than the faster click rate. Further, faster stimulus rates tend to reduce the clarity and reproducibility of evoked potential responses (Hood, 1998). Hence, a slower stimulus rate should be considered when obtaining a BIC for more distinct morphology and repeatability.

A visible and measurable BIC was obtained from 45 of the 47 subjects. The latencies and amplitudes of the most robust peaks within this component were measured and analyzed as an effect of increasing stimulus rate. The results of this study indicated that the absolute value of latency increased as the click rate increased. Similar results have been demonstrated in the past in humans (Don et al., 1977; Thronton & Coleman, 1975), and in cats (Shipley et al., 1984). There was a decrease in amplitude as the rate increased; however, this did not reach statistical significance. Thus, a slower stimulus

rate should be considered to obtain clear BIC waveforms. The disadvantage of using a slower stimulus rate is the increase in the amount of time in the recording process.

### Summary

The present study suggests that the BIC may be obtained in the majority of young individuals with normal hearing. The pattern of the BIC changes as a function of stimulus rate. A slower stimulus rate may very likely reveal more components of the waveform, as well as improve the morphology of the BIC. The fact that the BIC occurs at the level of the lateral lemniscus where it terminates in the contralateral inferior colliculus (ABR waves IV-VI), indicates that it may be used as an estimate of binaural interaction in patients with suspected lesions to the auditory system. The use of this tool may currently be restricted to young patients with normal hearing, thus more research should be attempted in the study of BIC in other age groups and patients with various degrees and configurations of hearing loss. These data may then be combined to formulate a clinically applicable electrophysiological index of binaural neural processes.

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