Rate, Frequency, and Intensity Effects on Early Auditory Evoked Potentials and Binaural Interaction Component in Humans

Teralandur K. Parthasarathy*
George Moushegian†

Abstract
The binaural interaction component (BIC) of the auditory brainstem response (ABR) and BIC of the frequency-following response (FFR) to tonal stimuli were studied in normal-hearing adults. The ABR and BIC latencies from all subjects were consistently shorter to the click-like sound than to the 2.0 kHz tone burst. Increasing stimulus presentation rate produced longer latencies and diminished amplitudes of ABR and BIC waveforms. The consequences of rate changes were independent of sound level. The FFR and BIC latencies to low-frequency tone bursts (0.5 and 1.0 kHz) were minimally affected by rate, but their amplitudes were modified. The results are consistent with and reflective of the functional characteristics of lower brainstem auditory neurons. The results provide evidence that the BIC to tones is differentially sensitive to the rate, frequency, and intensity of sounds other than clicks.

Key Words: Auditory brainstem response (ABR), binaural interaction component (BIC), frequency-following response (FFR)

The auditory brainstem response (ABR) is a transient response reflecting predominantly neural activity synchronized to the onset of the stimulus (Picton et al., 1974). However, the frequency-following response (FFR) is a sustained response, the waveform of which mimics the frequency of the stimulus, reflecting neural activity synchronized to the individual cycles of the low-frequency stimulus. Dobie and colleagues (Dobie and Berlin, 1979; Dobie and Norton, 1980) invoked a technique, first described by Kemp and Robinson (1937), whereby a waveform termed the binaural interaction component (BIC) is derived by subtracting the summed monaural from the binaural waveforms of the ABR. Both the ABR and BIC are used as indices of neural activity emanating from the cochlea and lower auditory brainstem. Furthermore, aspects of these waveforms reflect sequential and parallel neuroelectric activity from the superior olivary complex (SOC), the site where initial coding of binaural sound parameters occurs.

Bilaterally innervated neurons within the inferior colliculus (IC) and the SOC respond in diverse and complex ways to binaural sounds (e.g., Rose et al., 1966; Moushegian and Rupert, 1970a). For these reasons, implementation of ABR and BIC research to the subtleties of sounds has been difficult. Another obstacle is that the BIC is not a robust response; to enhance it, changes in click spectrum and number of stimulus presentations have been used. Gardi and Berlin (1981) state that the BIC is a consequence primarily of high-frequency energy. Wilson et al. (1985) confirmed this, but argued that mid-frequency stimuli also contribute to the generation of the BIC. Wrege and Starr (1981), however, believe that the BIC is essentially of low-frequency origin. Thus, results from human subjects regarding the frequency specificity of the BIC continues to be controversial.
Repetition rate increases have been invoked to improve the BIC. This manipulation could have serious consequences, since ABR threshold, morphology, peak latencies, or amplitudes are altered substantially by rate changes (Thornton and Coleman, 1975; Pratt and Sohmer, 1976; Don et al, 1977; Klein and Teas, 1978; Wilson et al, 1985), but the effect of rate on BIC/ABR at different frequencies and intensities has not been reported and thus merits further investigation. Studies of such parametric effects could be beneficial in suggesting procedural strategies that may enhance BIC recording.

Sounds having greater durations than clicks have been used in order to ascertain the role that specific frequencies play in the generation of BIC in scalp recorded ABR and FFR (Moushegian et al, 1973) and to ascertain also how repetition rate and intensity interact in evoking BIC waveforms. The objective of the present research, therefore, was to determine the effect of stimulus rate, frequency, and intensity on the ABR, the FFR, and the BIC.

METHOD

Subjects

Five normal-hearing subjects, ranging in age from 20 to 30 years, participated in this investigation. The inclusion criteria were: (1) absence of neurologic disorders and recently diagnosed otologic problems; (2) hearing sensitivity better than 20 dB HL for both ears at octave intervals between 0.25 and 8.0 kHz; (3) interaural sensitivity differences of 5 dB or less at each frequency; (4) middle ear pressures less than 50 mm H2O in each ear and no greater than 50 mm H2O between ears; and (5) the presence of contralateral acoustic reflexes at 100 dB HL (ANSI, 1969) for 0.5, 1.0, and 2.0 kHz tones.

Equipment and Procedures

The linearly gated stimuli were 5 cycle tone bursts at 0.5, 1.0, 2.0 kHz, and a 2.0 kHz click-like sound, presented at 85 and 100 dB rms SPL and at rates of 10 and 40/sec. They were generated by a frequency synthesizer (Rockland, 5100), and always turned on at the same onset phase (monaural and binaural). The outputs were fed through programmable mixer switches, attenuators, and impedance matching transformers to earphones shielded with mu-metal and fitted with MX 41/AR cushions. The sounds were monitored on an oscilloscope throughout the recording sessions. Responses were averaged by a microcomputer. Evoked responses were displayed on-line by a graphics terminal. All of the waveforms were stored for subsequent off-line inspection and analysis.

Gold-plated electrodes were attached to vertex (Cz, active), neck (C7, reference), and forehead (ground); impedances between all pairs of electrodes were always less than 5.0 kOhms, and differences between any two were less than 1.0 kOhm. Impedances were constantly monitored to assure consistency of recording. The background electroencephalographic (EEG) activity was amplified (100,000) with filter settings between 0.1 and 3.0 kHz (Grass, P511J). The recording time base was 15 msec with a resolution of 50 µsec per address. Two replicable waveforms were obtained for each stimulus condition from all subjects (N = 2000) and stored on disk (Kennedy, 5300). An X-Y plotter (Hewlett-Packard, 7475A) was linked to the computer, providing hard copy of waveforms. Computer programs were available to add or subtract any of the ABR and FFR waveforms. The derived binaural interaction component (BIC) was obtained by subtracting the summed monaural (SM) from the binaural (B) response.

RESULTS

Averaged Waveforms

Small differences in the parameters of a stimulus are readily reflected in brainstem evoked responses. Figure 1 illustrates ABR and BIC waveforms for 100 dB SPL at two rates, to
Figure 2  A, Waveforms from one subject of summed monaural (SM), binaural (B), and binaural interaction component (BIC) to 85 dB SPL (0.5 kHz, 4/2/4 msec envelope) and two presentation rates and B, same except that stimulus is 1.0 kHz, 2/1/2 msec envelope.

2.0 kHz click-like sounds (0/0.5/0 msec envelope) and 2.0 kHz tone bursts (1/0.5/1 msec envelope). The waveform to the 2.0 kHz click-like stimulus is indistinguishable from a typical ABR; it is apparent too that wave III and V latencies and amplitudes are noticeably compromised at the faster rate (see Fig. 1A). When a 2.0 kHz tone burst is the stimulus, components appear in the waveform that were not elicited by the click-like sound (see Fig. 1B). Increasing the rate from 10 to 40/sec resulted in the loss of some early components of the summed monaural and binaural waveforms, and a reduction of amplitudes and prolongation of latencies. Finally, the binaural interaction components are also modified by stimulus rate and spectral differences.

Figure 2 displays waveforms at 85 dB SPL for 0.5 and 1.0 kHz tone bursts, at two rates. The

Figure 3  A and C, ABR mean wave III, V, and BIC latencies; and B and D, amplitudes as a function of rate on summed monaural and binaural waveforms at 85 (open symbols) and 100 (filled symbols) dB SPL (2.0 kHz, 0/0.5/0 and 2.0 kHz, 1/0.5/1 msec envelopes).

Figure 4  A and C, FFR mean latencies; and B and D, amplitudes of vertex positive peaks (P1, P2, P3, and P4) and binaural interaction component (A, C, and E) at 10 and 40/sec (open and filled symbols, respectively). Stimulus frequency, 0.5 kHz (4/2/4 msec envelope). Parameters represent summed monaural (circles), binaural (squares), and BIC (triangles). BICs (A, C, and E) are represented sequentially (triangles).

Figure 5  A and C, FFR mean latencies; and B and D, amplitudes of vertex positive peaks (P1, P2, P3, and P4) and binaural interaction component (A, C, and E) at 10 and 40/sec (open and filled symbols, respectively). Stimulus frequency, 1.0 kHz (2/1/2 msec envelope). Parameters represent summed monaural (circles), binaural (squares), and BIC (triangles). BICs (A, C, and E) are represented sequentially (triangles).

231
waveforms closely mimic a FFR in which the peaks occur at the period of the stimulating frequency. This observation also applies to the waveforms evoked by low-frequency stimuli, where the waveforms P1, P2, P3, P4, and the BIC peaks (A, C, and E) are separated by 2.0 and 1.0 msec latencies for 0.5 kHz and 1.0 kHz tone bursts respectively. Increasing the repetition rate from 10 to 40/sec altered amplitudes of the FFR and BIC waveforms but not their latencies.

**Latency and Amplitude Analyses**

Summaries of ABR latency and amplitude results for summed monaural and binaural waves III and V as well as BICs at two rates and intensities are displayed in Figure 3. For auditory brainstem responses to a 2.0 kHz click-like sound and 2.0 kHz tone burst, the summed monaural and binaural waves III and V, and the BICs had shorter latencies at 100 than at 85 dB SPL. Increasing the repetition rate from 10 to 40/sec resulted in a differential latency and amplitude changes in ABR and BIC waveforms.

Summaries of FFR latency and amplitude results for summed monaural, binaural peaks (P1–P4), and BIC (A, C, and E) at two rates and intensities to 0.5 and 1.0 kHz tones, are displayed in Figures 4 and 5. The latencies of the summed monaural and binaural peaks P1–P4 were shorter at 100 than at 85 dB SPL. However, the amplitudes of the summed monaural and binaural peaks P1–P4, and binaural interaction component (A, C, and E) were not larger at 100 than at 85 dB SPL for 0.5 and 1.0 kHz tone bursts. This finding shows that 15-dB level differences affect the amplitudes of the waveform components in a similar fashion. Further, increasing the repetition rate from 10 to 40/sec resulted in a differential amplitude reduction of the FFR and BIC waveform peaks. However, an increase in repetition rate did not produce latency shifts for FFR and BIC waveform peaks.

**Statistical Analysis**

The latencies and amplitudes of vertex positive waves III and V of the typical ABRs evoked by a click-like sound (2.0 kHz, 0/0.5/0 msec envelope) and a 2.0-kHz tone burst (1/0.5/1 msec envelope) were determined. For the BIC of these waveforms, latency of the negative peak (N1) and N1–P2, amplitude were noted (see Fig. 1). The low-frequency sounds, 0.5 and 1.0 kHz, produced FFR type vertex-positive peaks, P1, P3, P5, and P4. In the analysis of the BIC waveforms, the first three positive peaks (A, C, and E), three milliseconds after stimulus onset, were noted (see Fig. 2). In order to evaluate rate, frequency, and intensity effects on the evoked ABRs, FFRs, and BICs, two independent multivariate analyses of variance (MANOVA) for repeated measures were performed. Summaries of MANOVA results are displayed in Tables 1 and 2. A post hoc Tukey's multiple comparison test on all the interaction effects was calculated with the statistical significance level set at 0.05.

**ABR and BIC Waveforms**

**Rate Effects**

Figure 3 (A and C) illustrates ABR and BIC mean latencies as a function of repetition rate at 85 and 100 dB SPL, to 2.0 kHz click-like sounds and 2.0-kHz tone burst. The results of MANOVA (see Table 1) revealed a significant rate effect for summed monaural and binaural waves III and V. A significantly greater latency shift (0.4 msec) was observed for wave V, summed monaural and binaural than the latency shift of wave III (0.2 msec). These differences indicate that the

<table>
<thead>
<tr>
<th>Table 1 Results of MANOVA: ABR and BIC Latencies and Amplitudes versus Rate, Frequency, and Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>R</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>R x F</td>
</tr>
<tr>
<td>R x I</td>
</tr>
<tr>
<td>F x I</td>
</tr>
<tr>
<td>R x F x I</td>
</tr>
</tbody>
</table>

SM = summed monaural; BIN = binaural; BIC = binaural interaction component; L = Latency; A = Amplitude; R = Rate; F = Frequency; I = Intensity; s = significant (p < 0.05); and ns = nonsignificant (p > 0.05).
summed monaural and binaural wave III are more resistant to rate than wave V, summed monaural and binaural. For summed monaural and binaural III and V latencies, the rate x frequency, rate x intensity, and rate x frequency x intensity interaction effects were insignificant. Further, the analysis of variance for BIC latency revealed a significant interaction between rate and frequency. A post hoc analysis on the interaction effect showed that the BIC latency shift with increases in repetition rates is significantly greater (0.6–0.8 msec) to a 2.0 kHz tone burst than to a 2.0 kHz click-like sound. The frequency x intensity interaction effect was insignificant.

The results of MANOVA (see Table 1) indicated a significant intensity effect on ABR and BIC waveform latencies. The summed monaural and binaural waves III and V, and BICs had shorter latencies (0.4–0.5 msec) at 100 than at 85 dB SPL. Furthermore, except for summed monaural and binaural waves V amplitudes, the intensity effect was insignificant. This implies that the amplitudes of summed monaural and binaural waves III, and BICs did not significantly differ in amplitude with intensity. This difference is evidence that amplitude increases with elevations in intensity do not occur uniformly or in parallel for the several components of the ABR waveform.

**Frequency Effects**

The results of MANOVA (see Table 1) indicated that the frequency effect was significant for summed monaural and binaural waves III and V, and BICs. The latencies of the summed monaural and binaural waves III and V, and BIC were shorter (0.3–0.4 msec) to a 2.0 kHz click-like sound than to a 2.0 kHz tone burst. The frequency x intensity interaction effect was not significant.

Further, except for the summed monaural and binaural wave V amplitudes, the frequency effect was insignificant. The summed monaural and binaural wave V amplitudes to a 2.0 kHz click-like sound was significantly greater than to a 2.0 kHz tone burst. However, the amplitudes of summed monaural and binaural waves III, and BICs did not differ significantly between 2.0 kHz click-like sound versus tone burst. The frequency x intensity interaction effect was insignificant.

**Intensity Effects**

The results of MANOVA (see Table 1) indicated a significant intensity effect on ABR and BIC waveform latencies. The summed monaural and binaural waves III and V, and BICs had shorter latencies (0.4–0.5 msec) at 100 than at 85 dB SPL. Furthermore, except for summed monaural and binaural waves V amplitudes, the intensity effect was insignificant. This implies that the amplitudes of summed monaural and binaural waves III, and N_1–P_2 of the BICs did not significantly differ in amplitude with intensity. This difference is evidence that amplitude increases with elevations in intensity do not occur uniformly or in parallel for the several components of the ABR waveform.

### FFR and BIC Waveforms

**Rate Effects**

Figures 4 (A and C) and 5 (A and C) display FFR and BIC mean latencies as a function of repetition rate at two intensities, to 0.5 and 1.0 kHz tone bursts, respectively. The results of
MANOVA (see Table 2) revealed an insignificant rate effect for summed monaural and binaural peaks P1–P4 or the BIC. It appears, therefore, that the waveform peak latencies for low frequencies are more resistant to rate increases than those for high frequencies. The rate x frequency, rate x intensity, and rate x frequency x intensity interaction effects were insignificant, suggesting the absence of rate effects on FFR and BIC latencies for 0.5 and 1.0 kHz tones at either 85 or 100 dB SPL.

Figures 4 (B and D) and 5 (B and D) show FFR and BIC mean amplitudes as a function of repetition rate at two intensities, to 0.5 and 1.0 kHz tone bursts, respectively. A significant rate x frequency x intensity interaction effect exists for summed monaural and binaural peaks P2 and P3 (see Table 2). A post hoc analysis on the interaction effect indicated that the rate effect for 0.5 kHz tone burst at 100 and 85 dB SPL was significantly greater for the summed monaural and binaural amplitudes (P2) than the summed monaural and binaural P1, P2, and P3 amplitudes. However, for 1.0 kHz tone burst, the summed monaural and binaural (P3) amplitudes at 100 dB SPL were significantly reduced with an increase in repetition rate than the summed monaural and binaural P1, P2, and P3 amplitudes. Further, the analysis of variance results did not show a significant rate effect for either the summed monaural and binaural peaks P1 and P4 or the BIC.

**Frequency Effects**

The FFR and BIC waveform latencies for summed monaural and binaural peaks P1–P4 were significantly shorter to a 1.0 kHz than to a 0.5 kHz tone burst. The FFR waveforms were shortened by 0.45 to 3.9 msec whereas BIC ranged between 0.5 and 1.67 msec. A nonsignificant frequency x intensity interaction effect suggests that the FFR and BIC latency differences to 0.5 and 1.0 kHz tone bursts at 100 dB SPL were maintained at 85 dB SPL.

A significant rate x frequency x intensity interaction effect exists for summed monaural and binaural peak amplitudes P2 and P3 (see Table 2). A post hoc analysis on the interaction effect showed that the amplitudes of the summed monaural and binaural peaks (P2) at 100 dB SPL were significantly greater to 0.5 kHz than to 1.0 kHz tone bursts at 10/sec. However, the summed monaural and binaural (P2) amplitudes were significantly greater to 1.0 kHz than to 0.5 kHz tone bursts at 100 and 85 dB SPL at 10/sec repetition rate. Further, the analysis of variance did not show a significant frequency effect for either the summed monaural and binaural peaks P1 and P4, or the binaural interaction component. Thus, frequency changes apparently do not affect the various components of the FFR and BIC waveforms in a similar manner.

**Intensity Effects**

A significant intensity effect on latency exists for 0.5 and 1.0 kHz tone bursts. The latencies of summed monaural and binaural peaks (P1–P4), and BICs were significantly shorter at 100 than at 85 dB SPL. Further, analysis of variance (see Table 2) did not show a significant intensity effect for either the summed monaural and binaural peaks (P1–P4), or the BIC (A, C, and E).

**DISCUSSION**

The derived BIC in ABR and FFR may be obtained by subtracting the summed monaural from binaural waveforms. The frequency specificity of BIC from humans has been limited and controversial. Our results suggest that the BICs may be derived for low- and high-frequency sounds. The morphologic characteristics of the BIC to low frequencies resemble FFRs; they do not resemble BICs evoked by mid-to-high-frequency stimuli. Furthermore, the ABR, FFR, and BIC waveform peak latencies and amplitudes are differentially sensitive to stimulus repetition rate, frequency, and intensity.

Effects of repetition rate on ABR latencies for the 2.0 kHz click-like sound and tone burst were similar. With increasing rate, greater latency shifts were produced for the summed monaural and binaural waves V, than the latency shift for summed monaural and binaural waves III. These differences indicate that the summed monaural and binaural III are more resistant to rate than wave V. Similar latency shifts for wave III and wave I have been observed (Pratt and Sohmer, 1976; Chiappa et al, 1979; Stockard et al, 1979). The latency changes with repetition rate were independent of overall intensity. This supports an earlier study that showed increased rate effects on ABR latencies to be independent of click intensity over a range of 30 to 60 dB SL (Don et al, 1977). Thus, our results have shown differential adaptation properties of ABR waveform components.
Lasky and Rupert (1982) noted that wave V latency-rate functions parallel those for wave III. Such discrepancies between earlier studies and the present one are a consequence, in part, of the differences between the stimuli (e.g., 2.0 kHz click-like and tone bursts employed in this study versus clicks).

With increased rate, larger amplitude decrements were produced for summed monaural and binaural wave V than for the summed monaural and binaural waves III, and BIC, suggesting that wave V is more susceptible to amplitude reduction with rate increases than wave III and BIC. Thus, it appears that the centrally generated ABR wave V is more volatile for amplitude as well as latency changes with increased repetition rate than the peripherally generated ABR wave III.

These results are not in agreement with Picton et al (1974) and Pratt and Sohmer (1976) studies; they noted that although all of the wave amplitudes diminished, wave V was affected less than the earlier ones. They hypothesized that the relative stability of amplitude and narrow dynamic range of wave V is a consequence of more complex neural interconnections at rostral than caudal regions of the brain stem. Kevanishivilli and Lagidze (1979) have suggested that the long duration of wave V is indicative of a mechanism which is relatively resistant to desynchronization, despite peripheral adaptation processes. The discrepancies between the findings of these several studies regarding amplitude stability may be a reflection of the differences in sample size, as well as measurement parameters such as intensity, response filter settings, and mode of presentation.

The frequency effects on ABR and BIC waveforms have shown shorter latencies to a 2.0 kHz click-like sound than to a 2.0 kHz tone burst for summed monaural and binaural waves III and V, and BIC. The frequency effect is maintained at 85 and 100 dB SPL. The frequency content of the signal produces, as would be expected, a certain space-time pattern of basilar membrane motion, which in turn activates specific sets of neural elements (Don and Eggermont, 1978). The results are also in consonance with a study that reported 0.2 to 0.5 msec ABR latency increases with a 1.0 msec increase of rise–fall time (Stapells and Picton, 1981).

The frequency effect resulted in differential amplitude changes for ABR and BIC waveforms. Except for summed monaural and binaural wave V, the amplitudes of the summed monaural and binaural III, and BIC did not differ for a 2.0 kHz click-like sound or a 2.0 kHz tone burst. This finding is not consistent with those of Don and Eggermont (1978), who hypothesized that the same cochlear regions do not project to the lower brainstem sites from where waves III and V emanate. They postulated that the basal region of the cochlea has a greater effect on wave III than wave V. Finally, Wilson et al (1985) reported that the ABR and BIC amplitudes did not differ significantly to filtered clicks centered at 1.0, 2.0, and 4.0 kHz. They pointed out, however, that BIC waveforms evoked by high-frequency stimuli were more pronounced than waveforms evoked by low-frequency stimuli.

The intensity effects on ABR and BIC waveforms indicate that the latency-intensity functions of waves III and V, and the BIC are similar to those obtained by other investigators. The latency decreases (0.4–0.5 msec) with increasing intensity are consistent with previous accounts, which have reported latency decreases of 0.4 msec per 10 dB increase in click intensity (Hecox and Galambos, 1974; Dobie and Norton, 1980).

For low-frequency stimuli, the FFR and BIC waveform amplitudes, but not latencies, were more susceptible to rate increases. An analysis of the data for repetition rates of 10 and 40/sec for 0.5 and 1.0 kHz tones at either 85 or 100 dB SPL, did not uncover significant latency shifts for summed monaural and binaural peaks P1–P4, or the BIC. It appears, therefore, that the waveform peak latencies for low frequencies are more resistant to rate increases than those for high frequencies. A possible explanation for the lesser susceptibility of waveform peaks to increases in repetition rate is the presence of a large population of phase locking neurons in the superior olivary complex (e.g., Lavine, 1971; Rose et al, 1974). The encoding of stimulus phase is an apparent consequence of the secure synaptic organization of neurons within these lower brainstem auditory nuclei. Summation of the large excitatory postsynaptic potentials (EPSP) upon these neurons may give rise to large synchronized evoked responses, recorded at a distance. They constitute the neural component of the FFR, which seems to be more resistant to the adaptation mechanisms hypothesized by Sorensen (1959).

Furthermore, analysis of data for repetition rate produced differential amplitude reduction on FFR and BIC waveform components. The summed monaural and binaural amplitudes...
(P₂) for 0.5 kHz at both intensities showed significantly greater amplitude decrements than P₁, P₃, P₄, and the BIC. In contrast, at 1.0 kHz the summed monaural and binaural (P₃) at 100 dB SPL were reduced more than were the P₁, P₃, P₄, and the BIC. The results provide evidence that the effects of repetition rate, frequency, and intensity are interactive and have differential effects on the components of brainstem evoked waveforms. They are not unlike the responses of the lower brainstem auditory neurons to similar sounds. Differences in the adaptation of FFR waveforms to some extent can be attributed to the differences in the discharge rate and also the time course of synaptic events of neurons in the lower auditory brainstem (Moushegian and Rupert, 1970b).

The frequency effect on FFR (P₁–P₄) and BIC (A, C, and E) latencies showed significantly shorter latencies to a 1.0 kHz than to a 0.5 kHz tone burst. These findings are in consonance with those of Yamada et al. (1977), who noted longer waveform latencies as frequency was lowered. They are also in accord with those of Wilson et al. (1985), who reported longer response latencies to lower-frequency filtered clicks than to clicks of higher frequencies. However, the frequency effect was not evident for all the waveform peak amplitudes. Except for summed monaural and binaural peaks P₂ and P₃, the amplitudes of summed monaural and binaural P₂, P₃, and BIC waveform did not differ for 0.5 and 1.0 kHz tone bursts. It appears, therefore, that the frequency changes do not affect the various components of the waveform in a similar fashion.

Analysis of data for intensity showed significantly shorter latencies for summed monaural and binaural peaks (P₁–P₄) and BICs at 100 than at 85 dB SPL. These findings are compatible with those of Wood et al. (1979), who have reported that waveform latency changes to tone bursts (2–5 msec) were similar to the latencies obtained with clicks. However, the intensity effect on FFR and BIC amplitude was insignificant. This suggests that 15-dB level differences affect the amplitudes of the FFR and BIC in a similar fashion. All of our results clearly demonstrate that stimulus parametric changes, which certainly affect peripheral and central auditory mechanisms in a differential manner, are exhibited in features of the ABR, FFR, and BIC.

Acknowledgment. Professor A. L. Rupert assisted throughout this study. Ms. A. G. Shoup-Pecenka helped in manuscript preparation. Supported by the University of Texas at Dallas and the M. F. Jonsson Professorship.

REFERENCES


