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Asymmetric Frequency-Following Responses

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Abstract

This study offers evidence of asymmetry in the frequency-following response (FFR), a brainstem evoked potential that mimics stimulus frequency. The FFRs to stimulation of one ear compared to the other are shown to have latency and amplitude dissimilarities, as well as considerable variations in waveform characteristics. The findings were obtained from eight subjects. Tone bursts at 500 Hz were delivered to the right ear, left ear, and binaurally at three sound levels. With few exceptions, subjects had asymmetric FFRs at every sensation level (SL); at some, the sound to the left ear evoked a larger response than the same sound to the right; at other levels, the right ear FFR was larger than the left. The results provide evidence that cortical processing asymmetries must, to some extent, be reflective of asymmetric mechanisms within the lower brain stem.

Key Words: Brainstem asymmetry; frequency-following response (FFR)

It is generally accepted that anatomic and physiologic asymmetries exist at cortical levels of the central nervous system. Paralleling this view is the assumption that speech sounds are processed by different central structures and neural pathways than nonspeech sounds (Geshwind and Galaburda, 1987; Mattingly and Liberman, 1988; Efron, 1990). Although asymmetric processing is considered to be restricted to cerebral levels of the central nervous system, recent studies have proposed that asymmetry is characteristic not only of the cortical mantle, but also of the rostral and caudal brain stem (Efron and Yund, 1974; Ferraro and Minckler, 1977; Decker and Howe, 1981; Eidelberg and Galaburda, 1982; Berlin, Hood, and Allen, 1984; Efron, 1985; Bopanna and Moushegian, 1988).

In studying the auditory binaural interaction component (BIC) with a modified form of Dobie and Berlin's (1979) procedure, Decker and Howe (1981) noted that the slightest latency and amplitude variations between waveform peaks to right and left ear clicks resulted in sizable difference traces when summed monaural waveforms were subtracted from the binaural. They believed that these differences in the brainstem electric responses are indicative of auditory tract asymmetry and expressed doubt that the BIC is an indicator of neural interaction.

Berlin et al (1984) described asymmetries for middle latency and auditory brainstem responses (ABR). Their strategy and methods for defining asymmetry were complex, time consuming, and required great care to eliminate possible differences in the sounds presented to right and left ears. They surmised that asymmetry occurred between the second and fourth order neurons of the auditory neuraxis and could not be attributed to peripheral dissimilarities.

Recently, Spivak and Seitz (1988) statistically evaluated the similarities and differences between right and left ear evoked responses. They reported that a significant number of subjects, close to Decker and Howe's (1981) estimate, had asymmetrical ABR. The percentage of subjects exhibiting left/right asymmetries was dependent on sound level and ranged between 40 and 70 percent. They concluded that the variation in numbers of subjects showing ABR asymmetry was a con-

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sequence of unequal and nonlinear amplitude changes with intensity among subjects.

Lauter and Loomis (1986, 1988) investigated the inter- and intrasubject variations of the ABR. They reported significant interaural asymmetries within and between subjects for both latency and amplitude of the evoked waveforms. In contrast, DeVries and Decker (1988) did not observe asymmetries in the frequency-specific derived ABR to right and left ear sounds. Almost without exception, auditory brainstem research has used clicks as stimuli in addressing the asymmetry question. The studies have required complicated experimental designs and controls, varieties of stimulus paradigms, extensive analyses of response waveforms, and numbers of recording derivations.

This study was part of a project, designed in a lateralization paradigm, to examine the characteristics of the frequency-following response (FFR) to diotic and dichotic low-frequency sounds (Moushegian, Rupert, and Stillman, 1973). While acquiring monaural and binaural responses over a range of sound levels, considerable differences were seen to exist between right and left monaural FFR waveforms evoked by identical stimuli. Since such dissimilarities continued to appear as recordings were obtained from more subjects, the question of asymmetry was pursued; this report offers evidence of its existence.

METHOD

Subjects

Nine normal-hearing female subjects 20–30 years of age participated in this study. One of these served as a control for ascertaining earphone equivalences and replicability of waveforms after a lapse of 10 days. The hearing thresholds of the subjects were no greater than 10 dB HL (re: ANSI, 1969) at octave and interoctave frequencies from 0.25 to 8.0 kHz. In addition, the threshold differences between subjects and among right and left ear for 500-Hz tone bursts were no greater than 5 dB.

Instrumentation

A software program developed by the Callier Research Computer Facility enabled stimulus presentation, data acquisition, response averaging, data analysis, and waveform plotting. The software program for stimulus presentation controlled a frequency synthesizer (Rockland 5100) that generated the 500-Hz sine waves. The output was modulated to create a rise-fall time of 4 msec and a duration of 4 msec, fed to a programmable attenuator, and transduced by earphones (TDH 49) shielded with mu metal and copper to preclude generation of artifacts.

Recordings were obtained from subjects seated comfortably in an electrically shielded sound-treated double-walled booth. The resistances between any two of three electrodes, i.e., vertex (Cz active), the neck (C7 reference), and forehead (ground), were always less than 5.0 kOhms. A neck (C7) reference, rather than mastoid, was chosen to maintain recording symmetry, regardless of stimulated ear. The electroencephalographic (EEG) activity was bandpassed between 0.1 and 3.0 kHz, amplified by a factor of 100,000, digitized at a sampling rate of 20 kHz, and averaged over a time epoch of 20 msec. To obtain reliable and replicable waveforms, the artifact reject program discarded amplitudes greater than 2.5 volts peak to peak. All illustrated waveforms represent the sum of two traces; each was acquired by averaging the electrical activity to 1000 stimuli presented at a rate of 8/sec.

In evoked potential research, the variations in response waveforms preclude grouping of the results between and within subjects for easy and valid comparisons. To obviate this difficulty, each waveform was normalized by first integrating the evoked response waveform between 5 and 20 msec, the epoch during which the responses occurred. This was accomplished by summing all of the bin counts of the waveform, disregarding algebraic sign for each of the 299 bins (50 usec/bin) in the window between 5 and 20 msec. The ratio of this number to the integrated count for the right ear waveform at 60 dB was the normalized index, expressed as a percentage for the waveform being integrated. In this way, the amplitude variations between and within subjects were minimized.

RESULTS

Figure 1 displays waveforms to sounds at the right and left ears of eight subjects at three suprathreshold intensities. The easily discernible and minute characteristics of right and left waveforms have very obvious dissimilarities, regardless of the level at which a com-

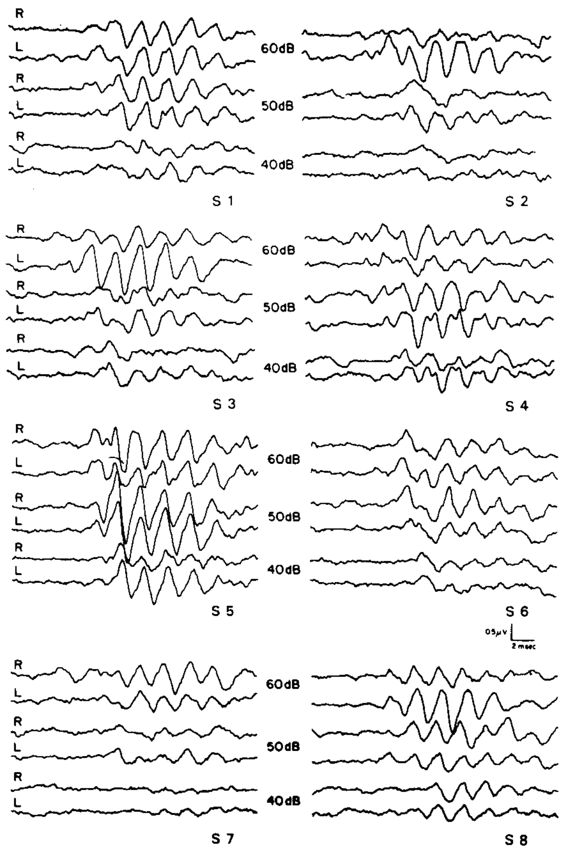

Figure 1 Waveforms of eight subjects to monaural right and left 500-Hz tone bursts at 60, 50, and 40 dB SL depicting asymmetries.

parison is made. Examination of the waveforms by subject shows that: (1) FFRs between subjects have many differences in their waveform morphologies, even though 500-Hz periodicity is maintained at all of these sound levels; (2) for a given level, amplitudes may vary as much as three times between subjects, even though thresholds for the stimulus were similar; and (3) none of the subjects had comparable or near comparable waveforms to left and right ear stimulation at any sound level. In addition to asymmetric differences between right and left waveforms, the responses, whether to sounds at right or left ear, exhibit nonlinear increases in waveform amplitudes and decreasing latency with increasing stimulus level. A statistical analysis of variance (ANOVA) for repeated measures on the integrated amplitude of monaural right and left ear FFRs was performed to determine the effect of sound level and ear differences. The results reveal a significant effect of sound level on FFR amplitudes ($F = 21.3$; $p = .0001$), as well as significant differences between right and left responses ($F = 5.5$; $p = .05$).

Further evidence for asymmetry was gathered from recordings obtained after reversing the earphones and also from the same subject many days and, in some instances, months later. In Figure 2, each of the paired waveforms (a–f) depicts the average of two evoked responses. The waveforms in a and b were recorded in sessions separated by 10 days. Furthermore, both traces in c are right ear responses to first one and then to the other earphone. In d, the two traces are from the left ear, driven successively by one phone, followed by the other. Finally, the last two sets of waveforms for right and left ear (traces e, f) are similar to c and d, except for sound level. Similar crosschecks were implemented randomly across subjects and the waveforms were visually inspected to determine repeatability. These data are evidence, therefore, for the replicability of the recordings and the validity of the phenomenon of lower brainstem asymmetric processing of a low-frequency sound.

Despite the variations among the eight subjects (Fig. 1), the data on asymmetry were grouped and summarized (Fig. 3). The two functions are simply the differences between the integrated binaural activity minus the integrated right ear response (B–R) for all of three sound levels and the integrated binaural response minus the left (B–L) at the same levels. Although the two functions are parallel, differ-

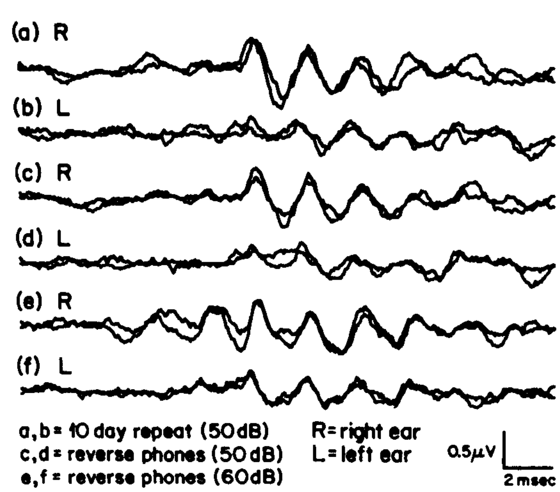

Figure 2 Replicability of waveforms from one subject to monaural stimulation.

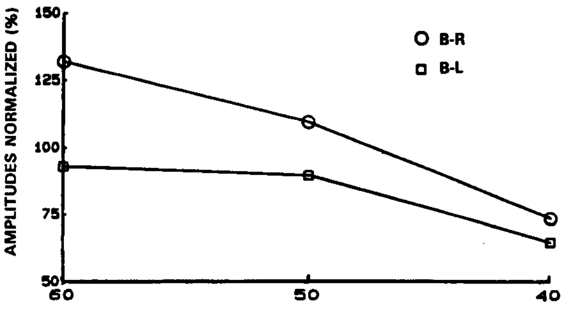

Figure 3 Asymmetric contribution of each ear to the binaural response. Normalized amplitude differences from eight subjects between binaural minus right (B–R) and binaural minus left (B–L).

ences in activity levels between them are significant (F = 31.9; p = .0008). The B–R function is greater than the B–L, an indication that the extent of evoked activity consequent to a left ear sound is greater than one to the right ear.

DISCUSSION

This study presents evidence of asymmetry for processing low-frequency sounds in the lower brain stem of the auditory neuraxis. The asymmetries are reflected in the latencies, amplitudes, and morphologies of the 500-Hz FFRs. The results cannot be easily compared to previous studies because the stimuli and recording procedures were different (Decker and Howe, 1981; Berlin et al, 1984; Spivak and Seitz, 1988). The number of subjects exhibiting asymmetries in the FFRs to the right and left ear, however, was considerably higher than to click-evoked ABRs (Decker and Howe [1981], 50%; Berlin et al [1984], 50%; Spivak and Seitz [1988], 71%; and DeVries and Decker [1988], 38%).

Since the FFR is a volume-conducted potential originating not rostral to the midbrain (Gardi, Merzenich, and McKean, 1979; Hoorman, Falkenstein, Hohnbein, and Blanke, 1992), these FFR asymmetries are an indication of underlying structural and functional diversities in the processes involved in their generation.

Finally, the results lend support to Efron's (1985) suggestion that hemispheric specialization may be due to asymmetrical processing at subcortical structures. He has implicated cortical centripetal and centrifugal pathways in the generation of asymmetries. This study provides evidence of its existence at considerably lower levels of the auditory pathway. These results indicate, in addition to asymmetry, that the left ear input is more dominant than the right during binaural stimulation, if it is accepted that integrated activity is an appropriate index of dominance.

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