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Concurrently Recorded Auditory Event-Related Potentials and Behavioral Responses to Dichotic CV Stimuli

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Abstract

Auditory event-related potentials (AERPs) were recorded concurrently with behavioral responses to dichotic CVs in 16 young, normal, right-handed, female subjects. The results showed the expected behavioral right-ear advantage and an N_{105}–P_{184} complex of significantly greater amplitude over the left temporal region than over the right. In another normal individual showing a consistent behavioral left-ear advantage, we found differences in AERP amplitude and morphology favoring right-hemispheric lateralization for speech.

Key Words: Auditory event-related potentials (AERPs), dichotic CVs, hemispheric laterality

It has long been known that the left hemisphere of most, but not all, normal, right-handed subjects is dominant in processing verbal or language-related stimuli (Bryden, 1965; Kimura, 1967; Kimura and Folb, 1968; Studdert-Kennedy and Shankweiler, 1970), while left-handed subjects comprise a more heterogeneous population (Dee, 1971). This lateral asymmetry in processing speech-like signals has been demonstrated behaviorally with dichotic listening tasks (Kimura, 1961; Berlin and McNeil, 1976; Berlin, 1977), pharmacologically with intracarotid Amytal injections (Penfield and Roberts, 1959), and physiologically with regional cerebral blood flow studies (Risberg et al, 1975) and positron computerized tomography (Mazziotta et al, 1982).

While, typically, left-hemispheric dominance for speech-like materials is reflected in a right-ear advantage (REA) for the correct identification of test items presented dichotically, not all individuals respond in this way (see Lake and Bryden, 1976, for example). Similarly, most, but not all, of the studies that have examined laterality for speech using auditory event-related potentials (AERPs) have shown greater levels of cortical activity recorded over the left hemisphere than over the right while the subjects attended to speech-like signals. Surprisingly, only a few AERP studies have used dichotic stimuli.

Haaland (1974) recorded AERPs at C_z, T_3, T_4, F_7, and F_8 (Jasper, 1958) in response to dichotic CVs in which only the initial consonant was varied. He reported that what he called the "P" component (160–306 msec) was larger over the right hemisphere than over the left for monaural, diotic, and dichotic modes of stimulus presentation, a finding which runs counter to virtually all other AERP studies using speech-like materials.

That same year, Neville (1974) reported asymmetries in AERP amplitude and latency that tended to complement clear behavioral asymmetries in supporting left-hemispheric dominance for speech in normal, right-handed subjects. She later (1980) reported the previously unpublished results of an attempt by Neville, Schulman-Galambos, and Galambos to replicate and extend these results using dichotically presented word pairs. Again, the results showed a significant behavioral asymmetry and, once more, a strong but nonsignificant tendency for AERPs to be larger when

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recorded from left rather than from right parietal areas.

DEVELOPMENT OF A DUAL TEST PROCEDURE

Background

Our review of the meager literature relating behavioral and electrophysiologic responses to speech-like stimuli piqued our interest in exploring this area of research. We developed a procedure by which both behavioral data and cortical AERPs could be recorded concurrently in response to dichotically presented CVs and the results compared.

Subjects and Test Environment

Sixteen right-handed, normal, adult females, aged 23 to 38, served as subjects. Each subject had normal hearing sensitivity and exhibited normal tympanograms. Each was a monolingual speaker of English who had no previous knowledge of the tasks employed. We skirted criticisms leveled at earlier research on AERP asymmetry by using only subjects who met a minimum criterion for right-handedness (second decile or higher) on a standardized test instrument, the Edinburg Inventory (Oldfield, 1971).

Following audiometric evaluation and the assessment of handedness, each subject was seated at a desk in an electrically shielded test room. A response sheet was taped to the desktop central to the subject's body position and line of vision to avoid possible effects of lateral eye deviation on the AERP recordings.

Test Materials and Procedures

The Dichotic Consonant-Vowel (CV) Syllable Test developed at Louisiana State University Medical Center (LSUMC) (Berlin et al, 1973) was chosen as the test instrument. Extensive use has established the consistency of this test in showing a right-ear advantage in groups of normal, right-handed subjects.

An original tape obtained from Kresge Labs at LSUMC was rerecorded with inaudible triggers inserted 100 msec before each stimulus pair, in order to provide a prestimulus baseline from which the peak amplitudes of the various AERP components could be measured. All test items were presented at 85 dB (±1 dB) sound pressure level (SPL). Stimulus channels and AERP recording channels were counterbalanced across ears and across subjects. Each subject checked off the pairs of stimuli that she heard.

Choice of an Index of Ear Advantage

Typically, in clinical studies, the algebraic difference between the proportions of correct responses for the two ears has been used as an index of laterality. Halwes (1969), however, pointed out that the upper limit of this index is determined by the overall performance level achieved by the subject, making comparisons among subjects difficult to interpret. In an attempt to overcome this constraint, Halwes expressed the observed difference between ears as a proportion of the maximally possible ear difference at a given performance level. He called this index "E." Repp (1977) noted that while "E" was independent of performance level, it failed to take into account the possible effect of guessing by the subject. Repp introduced a correction for guessing and called the resulting modified index "Eg." Our election to convert the behavioral raw data from our subjects to values of "Eg" was based on the above arguments.

Concurrently with acquisition of the behavioral responses, AERPs were recorded from electrodes at T_3 and T_4, referred to linked earlobes, with the nasion grounded. Interelectrode impedance was always less than 3000 ohms. Preamplifier gain was 5×10^4. Filter bandwidth was 1 to 100 Hz (half amplitude) with a roll-off of 6 dB per octave (simple RC characteristic). The EEG was sampled every 500 microseconds for a sweep duration of 500 msec. Artifact-rejection bounds were set at ±50 microvolts. Each AERP was based on 60 artifact-free sweeps. The digitized responses were stored on floppy disk and later transferred by direct modem to a remote minicomputer for digital filtering (low-pass, 30 Hz), baseline zeroing, peak-picking, and statistical analysis.

Behavioral Results

By design, all subjects admitted to the study showed a right-ear advantage in recognizing CVs during dichotic listening. This advantage ranged from 1 to 28 test items, with a mean of 9.4. The mean percentage correct scores were 69.2 and 59.2 for right and left ears, respectively. The corresponding Eg indexes for ear advantage ranged from 0.01 to 0.33, with a mean of 0.09.

Electrophysiologic Results

The grand mean AERP waveforms recorded in response to dichotic CV stimuli are presented in Figure 1. There was a consistent trend across subjects for components N_{105} and P_{185} to be larger in peak amplitude and shorter in latency over the left hemisphere than over the right hemisphere, but ANOVA revealed that only the difference between peak-to-peak amplitudes of the two N_{105}–P_{184} complexes was statistically significant ($F = 4.93$, $p \leq .04$). Only the mean latency of P_{30}, a component of the middle latency response or MLR, was found to be significantly shorter over the left hemisphere than over the right ($F = 4.91$, $p \leq .04$).

NOTABLE EXCEPTION TO THE GENERAL FINDINGS

Background

Many months after completion of the formal experiment, the first author had an opportunity to test a normal individual who showed a distinct left-ear advantage (LEA) on the dichotic CV task. The subject was a 23-year-old female who consistently demonstrated a LEA while serving as a practice subject for students enrolled in a class in diagnostic audiology.

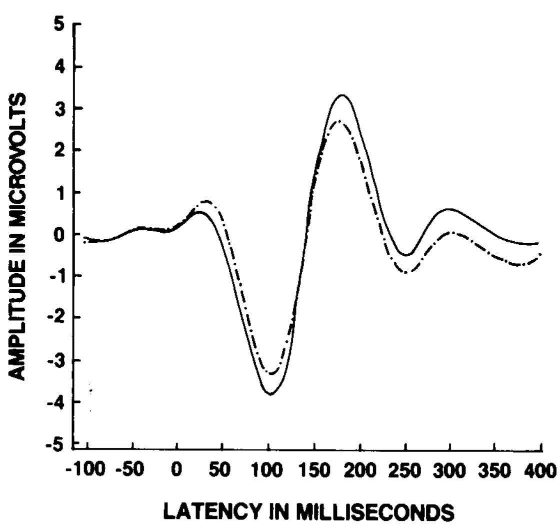

Figure 1 Grand mean AERP waveforms recorded from 16 normal, female subjects while they were actively engaged in identifying pairs of dichotic CV stimuli. The solid lines represent the responses recorded over the temporal region of the left hemisphere (T_3), the dashed lines those recorded over the temporal region of the right hemisphere (T_4).

There was a negative history of neurologic disease or of head injury, and, like all of the subjects in the earlier experiment, the subject was at least mildly right-handed, as reflected in a score on the Edinburg Handedness Inventory, which placed her at the second decile of the group upon which the test was normed. The young women's hearing sensitivity was well within normal limits, bilaterally; there was no evidence of a collapsing ear canal, and her sound localization ability appeared to be normal. Speech-recognition scores were excellent (100% RE; 96% LE; 50 dB SL) using the Auditec tapes of the NU-6 lists. The young woman's language and intellectual functioning were normal, and she denied any history of educational problems.

Procedures

The subject was evaluated using the same stimulus tapes, playback apparatus, and recording amplifiers described above, but signal averaging was accomplished on a microcomputer-based system, rather than the hard-wired system used previously. This change was not expected to affect the results significantly. Another change, but this time of probable significance, was the use of on-line, analog, low-pass filtering (30 Hz, RC characteristic), rather than the 0 phase-shift digital filtering employed previously, but which was no longer accessible to us. Use of the analog filters resulted in a prolongation of absolute response latencies. Pairs of electrodes were positioned in a coronal montage over homologous brain structures at C_3 and C_4, C_5 and C_6, and T_3 and T_4; all referred to linked earlobes, with the tip of the nose grounded.

During an initial run, the subject was asked simply to count, mentally, the number of pairs of CVs that she heard, without trying to identify any of them. The purpose of this run was to insure that any asymmetries in AERPs that occurred during active engagement in the CV identification task could be unequivocally attributed to hemispheric differences in cortical processing, rather than simply to the dichotic presentation of CV stimuli.

Behavioral Results

During a subsequent run using another randomization of the test stimuli, the subject scored 93 percent for items presented to her left ear and 60 percent for items presented to her right ear, a pattern of response virtually identical to that observed during prior behavioral testing. Her left-ear score was higher than that obtained by any member of the group showing a REA tested earlier, while her right-ear score fell well within the range recorded for the group. The resulting Eg of –0.22 reflected the strong left-ear advantage. The total correct response score achieved by the young woman was 153 percent, a figure substantially higher than the 130 percent reported by Berlin and McNeil (1976) as typical.

Electrophysiologic Results

The AERPs recorded from the single subject are shown in Figure 2. The traces on the left side of the figure were recorded during simple counting of the number of CV pairs heard; the traces on the right were recorded during engagement in the CV identification task. In both instances, the solid lines represent the responses recorded over the left hemisphere and the dashed lines those recorded over the right. The specific pairs of electrode sites used are indicated within each frame.

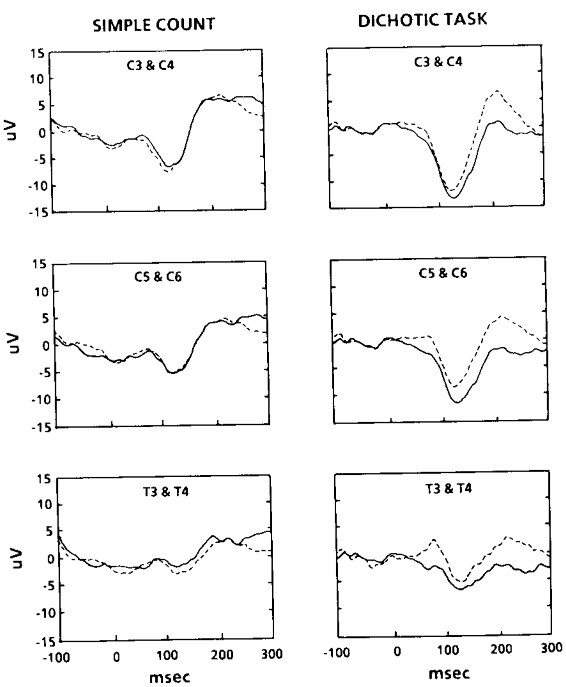

Figure 2 AERPs recorded from a normal, right-handed, female subject who repeatedly showed a strong left-ear behavioral advantage on the dichotic CV task. The traces in the three panels on the left were recorded from a coronal montage while the subject simply counted the number of CV pairs that she heard. Those on the right were recorded with the identical montage while she was actively engaged in the same CV identification task as the subjects represented in Figure 1. Specific electrode-recording sites are indicated within each frame. As in Figure 1, the solid lines represent the responses recorded over the left hemisphere, the dashed lines those recorded over the right hemisphere.

It can readily be seen that only negligible differences in AERP amplitude or morphology were observed across electrode pairs during simple stimulus counting, but that notable differences arose when the subject was actively engaged in identifying the CVs. Hereafter, only the latter results will be discussed.

The AERP waveforms appeared to us to be of greater amplitude and more clearly detailed when recorded from sites over the right hemisphere than over the left. The ripples in the waveform recorded at electrode sites T_3 and T_4 probably reflect myogenic activity originating in the temporalis muscles, a common finding in recordings made from these sites.

In contrast with the group data that showed significantly greater mean amplitude of the N_{105}–P_{184} complex recorded over the left hemisphere than over the right (7.7 μV at T_3 versus 6.6μV at T_4), the corresponding N_{130}–P_{214} amplitude for the single subject was larger over the right hemisphere than over the left at the same recording sites (4.6μV at T_3 versus 8.3μV at T_4), as well as at the other two homologous electrode pairs. The subscripted latency values used for the individual subject represent the mean peak latencies recorded over all six electrode sites.

Notably, the peak amplitudes of all three components recorded at left peri-Sylvian sites C_5 and T_3 were negative with respect to the baseline, leading us to conclude that these components may have been superimposed upon an underlying slow negative wave present at those sites. This might also account for the seemingly suppressed absolute peak amplitudes of the P_{80} and P_{215} components and the corresponding seemingly exaggerated absolute peak amplitude of N_{130} recorded over the same sites.

The individual and group AERP latencies could not be compared directly because of the differences in the low-pass filter phase-shift characteristics described above, but examination of the latency relationships existing within filter conditions was instructive. It is notable, for example, that the latency of the major negative inflection recorded from the individual was shorter over the right hemisphere than over the left, and that of the following positive inflection was shorter over the left hemisphere than over the right, precisely the reverse of the pattern reflected in the group mean data.

DISCUSSION

Behaviorally, our group of 16 normal, fe male subjects showed the expected right-ear advantage while engaged in a task requiring the identification of dichotically presented CV stimuli. Generally, the results appeared to be in good agreement with the information reviewed in a chapter by Berlin and McNeil (1976) that summarizes much of the work conducted in dichotic listening at the Kresge Auditory Research Laboratories at LSUMC in the early 1970s.

Based on their review of six different studies, Berlin and McNeil (1976) reported that the expected right-ear advantage for natural or synthetic syllables and rhyming CVC words presented to the right ear usually resulted in an accuracy of between 70 and 80 percent, while syllables presented to the left ear usually resulted in an accuracy of between 58 and 70 percent. Our mean scores of 69.2 percent for the right ear and 59.2 percent for the left ear fell at the lower end of these ranges. Nevertheless, they were superior to those of yet another study reported by Berlin and McNeil (1976) (see initial test results, their Fig. 10.2, p. 339), suggesting that the results may simply have been attributable to sampling characteristics associated with the relatively small number of subjects that we tested.

It is also possible that the scores achieved by our subjects may have reflected subtle performance deficits attributable to a variety of procedural factors. These might include degradation of the signal-to-noise (S/N) ratio (typically 3 dB) during the dubbing of analog tapes, less than optimal concentration on the experimental task by the subjects due to distractions (such as the need to maintain a specific posture so as to avoid disloding electrodes, etc.), and minor compression of right-ear scores attendant to the use of a high stimulus presentation level (see Cullen et al, 1974, for details).

In another mode of comparison, the difference of 10 percent observed between right- and left-ear scores appears to be in keeping with the 10- to 12-percent figure suggested by the ranges specified in the review article cited above. Finally, the mean sum of the scores correctly identified from both ears was 128 out of a possible 200 percent, in excellent agreement with the typical figure of "about 130 percent" given by Berlin and McNeil (1976).

Electrophysiologically, the mean amplitude of the concurrently recorded N_{105}–P_{185} AERP complex was significantly greater over the left hemisphere than over the right, and the latency of the principal negative component, N_{105}, tended to be shorter over the left hemisphere than over the right. These findings compare favorably with the trend observed by Neville (1974, 1980), and they are generally consistent with the pattern of left-hemisphere dominance for speech-like stimuli reflected in the electrophysiologic literature.

Interestingly, Neville (1980) speculated that despite their relatively weak lateralization, ERPs might be a more, rather than less, sensitive index of hemispheric specialization than the corresponding behavioral observations. She reasoned that the ERPs are time-locked to the presentation of the stimuli and that they are determined both by the immediate registration of information and by subsequent processing of task information. Behavioral measures, on the other hand, may only reflect later, response-related asymmetries. Presumably, this might make them dependent upon such confounding factors as response strategy, short-term memory, etc.

Perhaps this may account for the results noted in two individuals tested, but not included, in the final group, because they showed behavioral left-ear advantages (Egs of –0.06 and –0.09). Both were strongly right-handed, and they generated greater AERP amplitudes over the left hemisphere in response to dichotic CVs. These exceptions to the group performance are, nevertheless, consistent with the experience of Berlin and McNeil (1976), who estimated that perhaps 1 in 6 of their right-handed female subjects showed either no right-ear advantage or a clear left-ear advantage.

In distinct contrast with the above findings, we discovered a young woman who showed a marked left-ear behavioral advantage on the dichotic CV task and a corresponding asymmetry in AERPs favoring the right hemisphere, as reflected in greater response amplitude, shorter N_{130} latency, and generally clearer waveform morphology. We believe that this pattern clearly denotes right-hemispheric dominance for speech and that this finding is entirely consistent with the studies cited at the beginning of this paper, many of which attest to the existence of a certain degree of heterogeneity or plasticity of hemispheric lateralization for speech within the normal population.

CONCLUSION

The young woman's negative neurologic and educational history and her behavioral scores, which, in every instance, fell well within or even exceeded the range of those achieved by the group, effectively rule out auditory pathology. We speculate, instead, that she may simply be a representative of that heretofore unexplored 4 percent of the normal right-handed population estimated by Geschwind and Levitsky (1968) to be right-brained for speech. Further, we believe that the group and the individual findings provide complementary and converging support for the hypothesis that asymmetries in cortical processing may be disclosed by concurrent recording of auditory event-related potentials and behavioral responses to dichotic CVs.

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