Relationships Between Behavioral and Electrophysiological Measures of Auditory Comprehension

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Traditional methods used for study and evaluation of aphasia, such as the Porch Index of Communicative Ability (PICA) (Porch, 1967), the Token Test (DeRenzi and Vignolo, 1962), and the Revised Token Test (RTT) (McNeil and Prescott, 1978), require patients to make behavioral responses. From these behavioral output measures, investigators have tried to understand and explain the mechanisms underlying auditory comprehension deficits in aphasic patients (Schuell, 1964; Brookshire, 1973; Geschwind, 1965; Luria, 1966). However, since these methods require behavioral responses, it is difficult to determine whether the patient's deficit is more related to a disturbance at the input, integrative, or output side of the information processing system. Electrophysiological measures of the brain's response to external stimuli may provide a clearer picture of the deficits seen in aphasia, since they can directly assess cortical responsiveness. One electrophysiological measure, the event related potential (ERP), seems particularly promising for this purpose.

In the 1950's, signal averaging techniques were developed that were practical to use in a biomedical setting. This procedure allowed measurement of the brain's response to external stimuli, such as discrete tones and light flashes, by recording from electrodes affixed to the scalps of intact human subjects. The brain's response to the stimulus is extracted from unrelated random electrical activity, such as the ongoing electroencephalogram (EEG), by "time-locking" the signal averaging device to the stimulus presentations. Although the neural generators of all aspects of the ERP waveform are not clearly understood, it is accurate to say that the ERP represents the interaction of postsynaptic potentials of hundreds, if not thousands, of neurons involved in the processing of a particular stimulus. The ERP waveform is dependent on such factors as electrode location, types of stimuli presented, psychological factors involved in the processing of the stimulus, and the state of arousal of the subject at the time of recording. Using specifically defined stimulus conditions, it is possible to study the brain's response to external stimuli, as well as the influence of complex psychological factors such as attention and expectancy on stimulus processing (Goff, Allison and Vaughn, 1977; Shucard and Shucard, 1979; Thomas, Shucard and Selinger, 1980).

The ERP is generally described in terms of three parameters: polarity, latency, and amplitude. The symbols N and P are used to denote negative and positive shifts or peaks in the waveform, respectively (Goff et al., 1977). Figure 1 illustrates an ERP waveform obtained to discrete tones.

To date, there has been a sparsity of studies which have used electrophysiological measures such as the ERP in the study of aphasia, and these have focused on severity or recovery from aphasia (Greenberg and Metting, 1974; Liedtke and Morley, 1976; Kolman and Shimizu, 1972; Liberson, 1966).

The aim of this investigation was to compare data obtained from traditional behavioral assessments of auditory processing in left brain damaged aphasic patients (PICA, Subtest VI and X and the RTT) with the configuration of the ERP derived from a technique developed in our laboratory. The ERP technique described in this paper may be promising for the study of aphasia and brain functioning in general, in that it appears to assess relative degrees of activation of brain sites during the ongoing processing of information (Shucard, Shucard, and Thomas, 1977). Our procedure entails the recording of ERPs to task irrelevant stimuli which are superimposed on continuous task relevant information the subject is purportedly processing. Thus, this "Two Tone Probe Technique" uses irrelevant tone stimuli to probe brain functioning while subjects are engaged in processing other task related stimuli. Preliminary data are reported here for five left brain damaged patients and five age-matched controls who are part of a larger project that is currently being conducted in our laboratory.

Each subject completed a standard administration of the PICA and the RTT. Order of presentation of the PICA and the RTT was counterbalanced across subjects. Overall PICA scores were between the 80th and 85th percentiles for left brain damaged norms. Each subject had arrived at a stable overall percentile score on the PICA before testing was begun. Stability was defined as overall percentile scores which had remained within $\pm$ 5 percentile points for three consecutive months. All five subjects had only one known incident of brain damage and were premorbidly right handed. Subjects were not included who had a greater than 30 dB average threshold at 500, 1000, and 2000 Hz or a greater than 20 dB difference between each ear on a pure tone threshold test. The auditory ERP to pairs of tone stimuli were obtained under three experimental conditions from right and left temporal scalp electrode placements referenced to the vertex (T_4-C_z and T_3-C_z respectively, according to the International 10-20 system, Jasper, 1958).

The Baseline Condition consisted of four three-minute segments of taped "white noise" with randomly occurring clicks. Subjects were required to identify the presence of the random clicks by blowing on a temperature sensitive Grass Instruments Thermistor attached below the nares. The Verbal Condition consisted of four three-minute verbal passages presented to the subject. The subject's task was to identify the occurrence of a key word in each passage by blowing on the thermistor. Following each passage the subject was asked two multiple choice questions about the story. The Music Condition consisted of four three-minute taped musical selections. Here, the subject's task was to identify a short recurring musical theme which was part of the musical selection.

Clicks in the Baseline Condition, key words in the Verbal Condition, and musical themes in the Music Condition occurred on the average of 8 times in each 3-minute segment. Task irrelevant tone pairs superimposed on the ongoing white noise, verbal or musical stimuli, were used as probes to measure AERPs in all experimental conditions. All auditory stimuli were presented binaurally over headphones through a Sony MX-14 mixer.

Two amplifier channels of a Grass Model 78 polygraph with a bandpass of 3 to 100 Hz and a sensitivity of 7.5 µv/mm were used to record the EEG.

Sixty Hz noch filters were used. Outputs from the two amplifier channels were averaged by a Nicolet signal averaging system and plotted on a Hewlett-Packard 1004B X-Y recorder to provide a permanent record of the AERPs. Stimulus control and triggering of the signal averager were done by an Iconix System. Tones were generated by an IEC waveform generator. Two Bioelectric CA5 calibrators in series with each subject's scalp were used to place a 10 µv, 20 msec calibration signal on the left and right hemisphere recordings 240 msec prior to the onset of the stimulus.

Subjects were introduced to each condition with two sets of instructions. The first set was given live-voice by the experimenter; the second set of instructions were prerecorded on FM tape and delivered via the headphones. The instructions described the task and identified the target stimuli (clicks, key words or musical themes). The taped instructions also gave two actual examples of the target stimulus for each condition.

Each subject received three sessions of all three experimental conditions (Baseline, Verbal and Music) separated by seven days. Verbal and Music Conditions were counterbalanced across sessions, with the Baseline Condition always occurring first. For each condition, four AERPs were obtained (Tone 1 and Tone 2 responses from T_4-C_z and T_3-C_z placements). Only the amplitude data for one session obtained for Tone 2 peak 3 (a negative-going peak with latency = 257 msec S.D. ± 40.43) will be discussed here.

RESULTS

The distribution of PICA and RTT scores of the five patients reported here are shown in Table 1. While each of the five subjects' PICA mean raw scores were contained within a small range (14.4-15.0), their RTT scores indicated a wider range of deficits in auditory comprehension (10.85-14.28).

Table 1. Behavioral test data for five left hemisphere damaged aphasic patients.

Subject #	PICA VI		PICA X		RTT OVERALL	
	$\bar{X}$/S.D.	%ile	$\bar{X}$/S.D.	%ile	$\bar{X}$/S.D.	%ile
1	15.0/0.0	99	15.0/0.0	99	13.36/0.73	80
2	15.0/0.0	99	15.0/0.0	99	12.72/1.04	67
3	14.8/0.63	65	14.4/1.90	55	10.85/0.79	23
4	15.0/0.0	99	15.0/0.0	99	12.22/0.94	54
5	14.8/0.63	65	14.8/0.63	65	14.28/0.48	92

Qualitative examination of the electrophysiological data for aphasic subjects yielded three response patterns. Data from representative subjects illustrating these responses are presented in Figures 1, 2, and 3. The first AERP pattern, illustrated in Figure 1, closely resembled that seen in normal subjects in that (1) distinct AERPs were present from both left and right hemisphere placements; (2) recordings from each hemisphere exhibited qualitatively similar AERP amplitudes, and (3) recordings for each hemisphere exhibited the same number of AERP peaks and these occurred at similar latencies to that seen in the normal subjects. The aphasic subject whose AERP data are illustrated in Figure 1 had PICA 6 & 10 mean scores

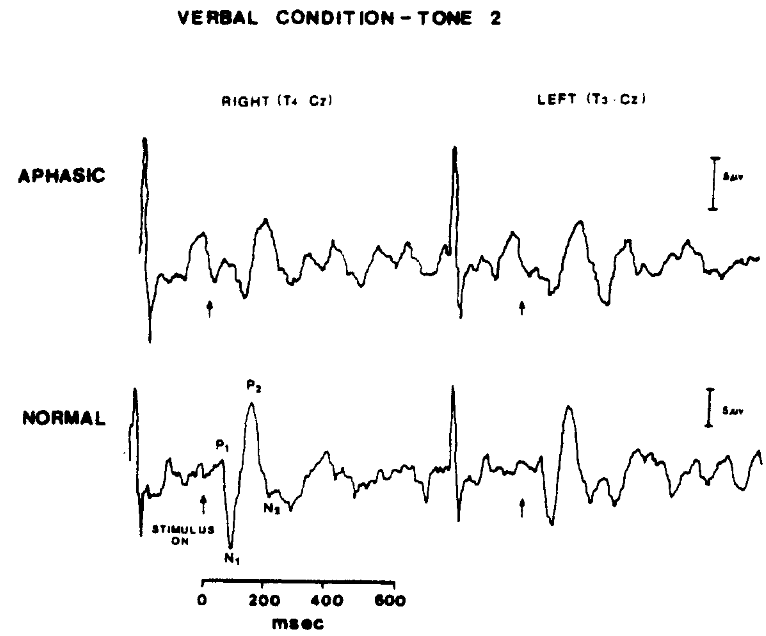

Figure 1. Auditory event related potentials to Tone 2 during Verbal Condition for a mild to moderately impaired aphasic patient and a normal subject. Note the symmetry between right and left hemisphere recordings. The vertical arrow indicates stimulus onset. The peak at the beginning of the tracing (prior to stimulus onset) is the calibration signal. P indicates positivity with respect to C_z. N indicates negativity with respect to C_z.

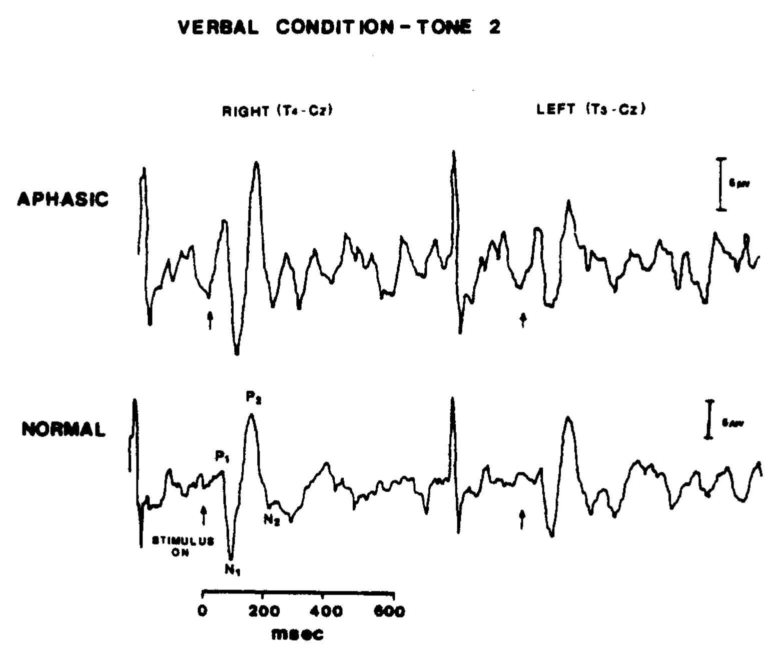

Figure 2. Auditory event related potentials to Tone 2 for the Verbal Condition recorded from right and left hemisphere locations in a severely impaired aphasic patient and a normal subject.

at the 99th percentile, and an RTT O.A. score at the 80th percentile. Two other subjects (subjects 4, 5) had similar AERPs to subject 1. Subject 4 scored at the 99th percentile on PICA subtests and the 54th percentile on the RTT. Subject 5 scored at the 65th percentile on the PICA subtests and at the 92nd percentile on the RTT.

The second response pattern, illustrated in Figure 2, is unusual in that it deviated from that of normal subjects and the first response pattern by exhibiting interhemispheric AERPs that were markedly asymmetrical. The AERPs from the particular patient shown (Subject 3) had a higher amplitude right hemisphere response in comparison to the left hemisphere response. Aside from this amplitude asymmetry, the AERP waveform was similar from both hemisphere recording sites and had the same number of peak latencies as that seen in the normals. This patient was the most severely impaired of the group, as indicated by the PICA and RTT scores (PICA 6 score = 65th percentile and PICA 10 = 55th percentile; RTT score = 23rd percentile).

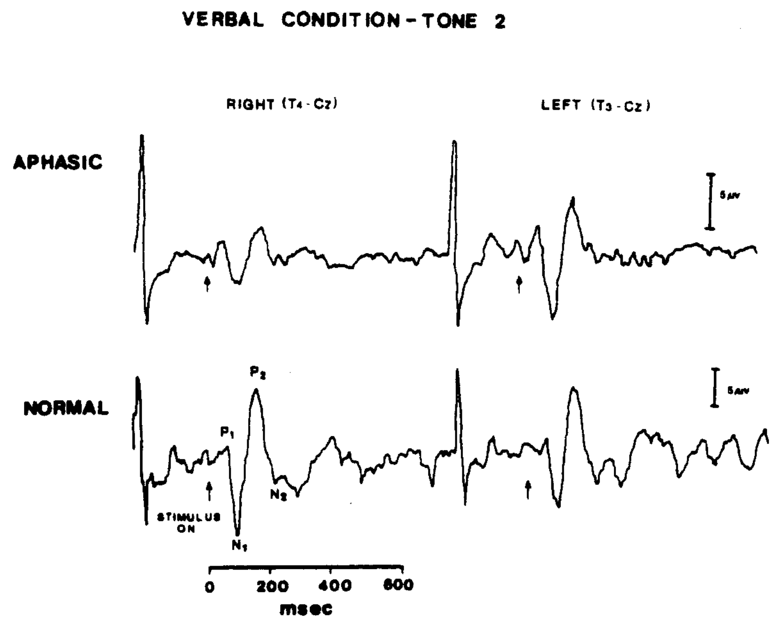

Figure 3. Auditory event related potentials to Tone 2 for Verbal Condition recorded from right and left hemisphere locations in a mild to moderately impaired aphasic patient and a normal subject. Note the attenuated right hemisphere response.

The last response pattern, illustrated in Figure 3, was unique in that the AERP asymmetry described for the second pattern was reversed, with the left hemisphere recording showing a higher amplitude AERP than the right hemisphere response. Aside from this amplitude asymmetry, the AERP waveform for this patient was similar for both hemisphere recording sites, with an equal number of peaks and similar latencies to those obtained for normals. This patient had PICA 6 and 10 scores at the 99th percentile, and an RTT score at the 67th percentile.

In order to more closely examine interhemispheric AERP relationships between normal and aphasic subjects, relative Peak 3 AERP amplitude differences between right and left hemisphere recording sites were obtained for the Verbal Condition by subtracting left hemisphere Peak 3 amplitude from right. Higher amplitude right temporal Peak 3 responses produce a positive difference score (D-score), whereas higher amplitude left hemisphere responses yield a negative D-score. Figure 4 illustrates the Peak 3 D-scores obtained for normal and aphasic patients. While four out of five normal subjects exhibited a higher amplitude left hemisphere response than right during verbal processing, aphasic subjects responded less predictably. Two aphasic subjects showed greater left than right responses, whereas three had greater right hemisphere responses than left. Comparisons between these AERP D-scores and the behavioral scores indicated that those patients who fell in the mild to moderate ranges on the behavioral measures (RTT = 54-92 percentile) exhibited, according to our evaluation, more normal differential hemisphere responding as indicated by AERP measures. For example, Subjects 1, 2, 4, and 5, who, according to the AERP data, were most similar to the normal subjects, had PICA and RTT scores in the mild to moderately impaired range; whereas Subject 3, who showed the most impairment on the behavioral tests, also showed a markedly attenuated left hemisphere AERP as compared to the right sided recording.

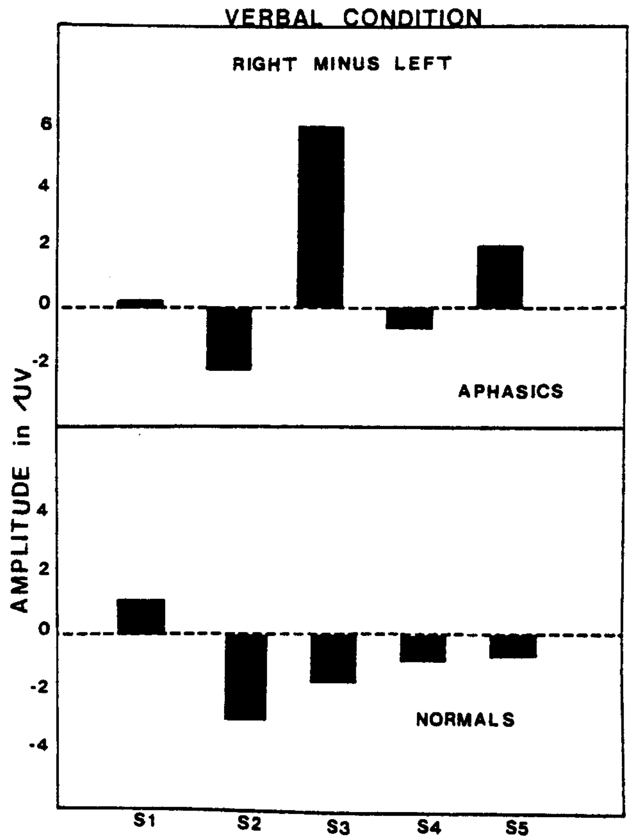

Figure 4. Relative Peak 3 AERP amplitude differences between right and left recording sites for the Verbal Condition in five aphasic and five normal subjects. Positive difference scores indicate higher amplitude right temporal responses. Negative difference scores indicate higher amplitude left temporal responses.

CONCLUSIONS

This preliminary report of electrophysiological correlates of auditory comprehension leads us to speculate about the technique's application to the study of the impaired auditory modality in aphasia. Comparing the AERP data with the behavioral assessments suggests that patients who tend to fall within the mild to moderately impaired ranges on behavioral tests of auditory comprehension have AERP responses that closely parallel those seen in normals. The two subjects who deviated most from this pattern must be considered separately. The subject exhibiting the increased left hemisphere response showed a D-score (-2.09 µv) which closely parallelled the AERP values for normal subjects. This subject's larger left hemisphere response may be indicative of his processing of verbal information with the hemisphere dominant for language. However, the largely attenuated right hemisphere AERP still may indicate a unique brain response to the verbal information. Conversely, the subject who was behaviorally most impaired and showed larger right hemisphere responses (D-score = 6.19 µv) may have been using relatively more of the minor hemisphere for language processing.

It is significant to note that those patients showing more left hemisphere responsivity during verbal processing (subjects 2 and 4) are those whose lesions were found to be more anterior, while those with greater right hemisphere responsivity during processing had more posterior lesions. (Lesion location was determined by CT scan and brain scan data.) Since the AERPs were measured over the superior temporal regions, these results, according to our thinking, seem to reflect relative intactness of auditory cortex involved in higher level information processing.

Although these findings are preliminary and are the result of testing a small number of subjects, the application of this methodology to the study of language deficits may provide information about mechanisms of auditory comprehension heretofore unattainable, thus allowing for more precise determination of the degree of functional deficit in auditory comprehension in aphasic subjects.

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DISCUSSION

Q: Were your normal subjects the same age as the aphasic subjects?

A: They were age matched. One of the reasons that we matched for age is that all of the data we had were from young normal (18-25 yrs) subjects. Since we were using older aphasic men we selected an older, matched group of normal subjects.

Q: Can you explain again the nature of the stimulus presentation?

A: Let me use the verbal condition as an example. Subjects heard a three minute listening comprehension story and they were told, for instance, that the word they were to listen for was "log." Log occurred perhaps eight times in the story. They listened to the story and blew each time they heard "log." In addition, there were 600 Hz, 71 dB tones superimposed on that information. The signal averager measured the brain's response when the tones occurred so that the tones become task irrelevant stimuli while they are processing ongoing verbal information.

Q: The tones occur whenever there is the word log?
A: No, the tones occurred every six seconds.

Q: You did not really ask your subjects to comprehend the passage, by asking them questions at the end. It sounds to me like a recognition task.
A: I did ask my subjects to comprehend the passage. They were asked multiple choice questions at the end of each passage--so it's a comprehension task in that sense. The reason they were asked to identify the words was so that we could be tuned in to whether or not they were attending to the task.

Comment: There's some interesting stuff along this line by Factor and Nagle. I believe they presented words to people in pairs and aksed them to make same-different judgments. The words were semantically related or unrelated, and they recorded evoked potentials. They found a distinct differential left hemisphere response with their normals when they were asked to make semantic decisions.

Comment: I think that comment is an important one, because you might call what you're looking at a transmission effect, and the variability that you're seeing between the hemispheres in some of the patients may have to do with lesion extent and density of lesions in primary cortex and not a comprehension or recognition phenomenon per se. It's an important distinction to make in that kind of a paradigm.

A: I think that to some extent that's what we're after.

Q: Have you run any of these patients on left-right ear effects and if not, what would you speculate you might see in patients showing right hemisphere processing?
A: I suppose that I could speculate that patients showing large right hemisphere response would show a dichotic left ear advantage. We have not run that.

Q: Some information suggests that for normals, if you present information which is meaningful semantically vs. nonsense material, that you will get a difference in terms of location of activation. It seems that you looked at averages in general. Did you look at the locus of the effect?
A: No, the only measurements we are looking at are the left and right temporal placements each referenced to the vertex, rather than a full topographical analysis.

Q: I was interested in the one patient who used the right hemisphere or had a higher potential in the right hemisphere. You indicated that he was more severely impaired than the other aphasic patients. Was he consistent in answering the questions and identifying the key words?
A: He was either good at getting the key words or answering the questions but not both. He never did both very well.

Q: How did most of your subjects do on your multiple choice questions?
A: They get about fifty per cent right.