Neurophysiological instrumentation for studying speech and language performance

Michael R. Seitz, Dalhousie University

Introduction

Many researchers and investigators interested in language have turned to linguistic theory in the hopes of finding a better theoretical basis for the study of normal and deviant language. In return, many of these researchers brought to the field of linguistic study different backgrounds and methodological expertise. In this article I will describe and discuss the potential usefulness of a relatively new technique for monitoring various waveforms of cortical activity that can be associated with specific aspects of speech and language performance. This technique has many names but essentially involves averaging a specific portion of the brain's EEG activity that occurs after the onset of a specified stimulus. The general name for this technique is Averaged Electroencephalic Response Technique or more universally known as the AER technique. This technique can utilize visual, somatosensory, or auditory signals as stimuli and the resulting AERs, while similar, display different wave forms. For my purpose in studying aspects of speech and language performance, auditory stimuli were best suited.

The AER Technique

Before discussing my particular use of the AER technique for studying speech and language performance I would like to briefly describe the technique itself. The

Averaged Electroencephalic Response (AER) to auditory stimuli is reflected in both latency and amplitude changes in the ongoing EEG activity that occurs in the brain's response to the stimuli. These changes in activity are normally too small to be seen in the on-going EEG, so to compensate for this low signal amplitude, a number of cortical brain wave samples, time locked to the stimuli are gathered and stored in a computer or a signal averager. These responses are all similar in that they are EEG activity triggered by the onset of the auditory stimuli. The resulting signal averaging allows one to observe if there was a specific neural response to the auditory signal or not. If the auditory signal is received by the brain, a particular kind of waveform will form. Averaging a number of these auditory stimulus presentations will clarify the response because the accompanying non-related cortical activity will be algebraically summed out. That is, these uninvolved portions of neural activity will be random relative to the specific auditory signal and thus cancel each other out.

Differences in AER Wave Components

There are actually four different sets of wave responses that can be generated to auditory stimuli. Each separate wave form reflects activity of different parts of the auditory pathway; each wave form has different latencies and amplitudes of response, each has different uses in studying auditory processing in general and language and speech particular. (See Picton and Hink, 1974, for more information on evoked potentials).

The four separate wave components are as follows:

1. The early components - these responses occur between the first and tenth millisecond after the onset of the auditory signal. These waves actually reflect the transmission of the beginnings of the auditory stimuli up the brainstem portion of the auditory pathway. At present they have little demonstrated use in language or speech performance paradigms but have tremendous potential for the testing of hearing levels of hard to test subjects, particularly newborns and young infants.
2. The middle components - these waveforms occur between ten and sixty milliseconds after the stimulus onset and reflect neural activity around the level of the thalamus and initial arrival of the auditory stimuli at the level of the primary auditory cortex in the temporal lobe. These waveforms are useful in testing hearing in subjects who are otherwise hard to test by normal behavioral means, i.e., the very young, the infirm or aged, the mentally retarded. So far, no one has explored these waveforms in terms of language performance, but there does seem to be some potential for certain speech perception paradigms.

3. The late components - these waveforms occur between sixty and three hundred milliseconds after the onset of the auditory stimuli. They reflect activity generated at the level of the cortex and are thought to come from the association areas of the temporal and partial lobes of the cortex. It is this waveform that I will be talking about in more detail later in this paper.
4. The contingent negative variation or CNV waveform occurs sometime after 500 milleseconds after the stimulus onset and is very effective in demonstrating attention and emotional states of the brain.

All in all, there are some 15 to 17 different wave peaks that are available to use, some more stable than others; each reflecting different aspects of neural or cortical activity in response to the auditory stimuli. While much is not yet known about these waveforms, it is important to note that these waveforms do vary systematically with changes in:

1. the stimulus itself
2. the response requirements of the experimental paradigm
3. changes in intensity or interstimulus interval of the signals
4. the presence or absence of expected signals.

One might ask, at this point, why should one try to use such a technique in the study of language. I offer the following reasons for my choice of the method:

1. The AER technique can largely by-pass skeletal (voluntary) motor output and, in this sense, is "culture-fair" and not under conscious control of the subject.
2. AER technique can provide convergent data with respect to other more conventional measures such as reaction time, sentence repetition or word recognition tasks.
3. The AER itself is a more immediate response (within the first 500 msecs after the stimuli) and may better reflect the immediate substraits of performance than the actual behavioral responses can.
4. The AER appears reasonably sensitive to gross differences in lateralized cerebral functioning.
5. The AER does not <u>require</u> a motor response and thereby can be useful with patients who cannot or will not response behaviorly.
6. Precise measurement can be made with respect to latency and amplitude of specified portions of the waveform.
7. Most important of all - while being a bit uncomfortable, the AER technique does not involve

personal danger or a health hazard.

Review of Relative AER Research Relating to Cerebral Processing

In the last ten years the AER technique, utilizing the late components primarily, has been utilized as a means of assessing more complex aspects of cerebral processing. Greenberg and Graham (1970) found that the AER amplitude decreased in the left hemisphere during repeated presentations in a paired-associate consonant-vowel syllable learning paradigm, while the amplitude in the right hemisphere, initially relatively small, remained unchanged. Cohn (1971) compared AER's to clicks with AERs to monosyllabic words. He found distinctive wave forms in the right hemisphere in response to click stimuli that were not present after presentation of the monosyllabic words, as well as larger left hemisphere AERs to monosyllabic words. Morrell and Salamy (1971) noted that the N_1 peak of the left hemisphere AERs was greater than the same peak of the right hemisphere when nonsense syllables were the stimuli, while Wood, Goff and Day (1971) reported a significantly larger left-hemisphere AER for a phonetic judgement task but not for a pitch judgement task. As part of a larger study, Matsumiya et al (1971) found larger left hemisphere AERs when their subjects used verbal mediation to accomplish the experimental task. Ruhm (1971), like Cohn (1971), found larger right-hemisphere AERs when clicks were used as acoustic stimuli.

In summary then, those studies that used verbal stimuli to elicit AERs found greater left hemisphere activity while those studies that used nonverbal stimuli found larger right hemisphere AERs. Thus, the AER technique was found to be responsive to verbal stimuli and potentially useful as a tool for the study of speech and language processing.

As was stated earlier, the AER wave forms that I have been using are the late components, primarily the N_1-P_2 portion. I have used these particular wave forms for the following reasons: The N_1-P_2 complex

1. is one of the larger and more easily describable portions of the AER with a long history of past research utilizing this wave form (see studies reviewed above).
2. is known to arise from the cortex proper and not from lower portions of the auditory pathway such as the brainstem.
3. has already been found to reveal differences in hemispheric response patterns and is capable of revealing differences in stimuli or response requirements used.
4. is not under voluntary control of subjects that is quick enough to give excellent indications of response patterns in subjects prior to any motor response accompanying the tasks.
5. is a more stable, less variable, waveform between subjects in any experiment.

AER Use In Speech And Language Performance Paradigms

My initial research in this area began back in 1968. In those first studies (Seitz 1972, Seitz and Weber 1972) I used the AER technique as a monitor of the EEG activity of 24 subjects whose task it was to locate a click superimposed on sentences (Fodor and Bever, 1965) but using two different response methods: (i) writing out the complete sentence first and then marking the location of the perceived click, (ii) marking the location of the perceived click on typed scripts of the stimulus sentences. The clicks themselves were located either before the major costituent break (MCB) in the MCB or after the MCB in all the sentences. All subjects heard the same stimulus tapes and only the response requirements differed.

In the initial studies, equipment limitations permitted the monitoring of only one hemisphere, so the hemisphere contralateral to the ear receiving the click was monitored on the theory that the contralateral pathways were primary in man. Separate AERs were obtained for each click location i.e., 1 AER for before break clicks, 1 AER for in break clicks, and 1 AER for after break clicks.

I hypothesized that if the clicks were treated as part of the overall linguistic process in the write-out group, then the latency to N_1 would be shorter and the amplitude larger in the left hemisphere than in the right hemisphere. The results confirmed this hypothesis. The left hemisphere AERs as a group were significantly shorter in latency and larger in amplitude than the right hemisphere response. Thus this study confirmed systematically different hemispheric activity in syntactic processing.

However, this initial study had one weakness. Owing to limitations of equipment available, only responses in the hemisphere contralateral to the click were monitored since this hemisphere is believed to be the primary projection area of the auditory cortex (Kimura, 1967). To correct this obvious weakness a new study was designed to replicate the initial results (Seitz, 1976), this time monitoring both hemispheres and adding a control condition in which the click was presented in isolation as well as in the linguistic paradigm.

The equipment for this experiment was similar to the first but now two EEG channels were recorded and all analysis was done off line.

The results of the second experiment confirmed the initial finding that linguistic constraints can be reflected in differences in AERs. However in the second experiment, a more controlled and better equipped one, the significant left hemisphere response to clicks occurred only for the write-out group and not the marking group. In addition analysis of hemispheric response patterns to the clicks revealed a significant advantage for the contralateral pathways over the ipsilateral pathways in terms of latency of response but not amplitude (Mononen and Seitz, 1977). These two studies thus help confirm that AERs can reflect changes in response requirements and can be used to measure different language processing activity occurring under different psychological response requirements.

The next experiment utilizing the AER technique that I wish to discuss is one that I did with a number of colleagues and concerns the question of language processing activity in bilinguals (Genesee et al, 1978).

As I have indicated earlier, a wide variety of evidence indicates that the left hemisphere in man is "dominant" for language. This evidence, however, is based on persons possessing one language. The Genesee et al (1978) research project investigated the language processing of bilinguals by studying their patterns of neural activity when processing verbal material presented in each of their two languages, French and English.

Eighteen adults, equally fluent in English and French, participated in this language recognition experiment. Subjects were placed in subgroups on the basis of when they had acquired their second language. One group (infant bilinguals) learned both languages from infancy, a second group (childhood bilinguals) acquired skill in the second language at approximately 5 years of age, and a third group (adolescent bilinguals) became bilingual at the high school age level.

The AER equipment set up was basically the same as in the previously discussed studies except that a reaction time (RT) condition was added as a behavioural measurement along with the AERs. Thus, both a neurophysiological measurement (the AER) and a behavioural measurement (the RT condition) were utilized in this study.

Subjects were required to press a RT key to indicate whether each word, presented through earphones, was English or French. While performing that task, their left and right hemisphere EEG activity was monitored and recorded via surface electrodes to provide AER (average electroencephalic response) comparisons of the language processing activity of the two hemispheres when French and English words were presented.

The results indicated that bilinguals, as a group, demonstrated the expected characteristic pattern of neural organization for language: the left hemisphere AERs were significantly faster than those of the right hemisphere for both French and English words. This left hemisphere advantage in N_1 latency, however, was limited to those who had been infant or childhood bilinguals. Adolescent bilinguals demonstrated a faster <u>right</u> hemisphere response to both French and English words under the same test conditions. Furthermore, the adolescent bilinguals had generally faster cortical response to N_2 than the other two groups.

Since all Ss were required to meet strict criteria for equivalence of fluency in the two languages, these results could not be explained in terms of differential language skill. Implications of the results for language processing in bilinguals are discussed in our paper which is published in Brain and Lanugage (1978).

Thus far, I have demonstrated how the AER technique can be used to study various aspects of speech and language performance. With minor modifications the technique can be adapted to measure motor speech activity itself.

A Ph.D. student of mine, Ms. Rosalee Shenker, and I are doing just that with groups of normal speakers and stutterers. In this paridigm we have the subjects read single words beginning with the same phonemes (the stop-plosive set) and record their utterances and concurrent EEG activity. Later we go back and average all words beginning with /p/, /b/, /t/, etc., by looking at a time base and one second prior to speech onset and one second after speech onset.

While the data analysis for Ms. Shenker's study is not yet complete, I can tell you that AER technique did work and provided a method for viewing cortical activity prior to speech activity as well as during speaking itself.

At present, a group of us at Dalhousie University have begun to explore other wave component response as well as the late components. We have a number of studies under way in our lab; the most noteworthy is the multiple use of various AER wave forms in the study of auditory processing in a group of dyslexic children. Past experience has indicated the appropriateness of the AER technique for such studies. However, future data analysis will determine its usefulness in such studies.

Conclusion and Limitations of the AER Technique

I hope these example uses of the AER technique have demonstrated the potential of the technique in future speech and language studies. However, I feel that I would be remiss in my discussion if I did not also list some of the drawbacks of the technique as well:

1. The basic drawback is that the AER reflects most stably activity occurring around 100 to 300 msecs. after the onset of the stimulus. Thus this technique really is not able to respond to complete individual words within sentences because it is too quick a response.
2. The technique requires that a sufficient number of trials of a very similar nature be available in the experiment to provide the necessary sample size needed for the averaging aspect to work effectively. This would mean one would need around ten to thirty repetitions to obtain good signal averaging benefits. Often this restriction limits the type

of stimuli to be used.

3. The cost of such equipment runs from $16,000. to the $20,000. plus price range. Either one must have a very rich uncle, understanding university or department, or a very well written grant to provide this equipment.

In closing, I would like to emphasize that the major limitation of the technique lies not in the instrumentation itself, but rather in the knowledge, ability, and creativity of its users. Therein lies the limitation of my own research.

References

Cohn, R., 1971. Differential Cerebral Processing of Noise and Verbal Stimuli. Science, 172, 599-601.

Fodor, J. and T. Bever, 1965. The Psychological Reality of Linguistic Segments. Journal of Verbal Learning and Verbal Behavior, 4, 414-420, 1967.

Genesee, F., J. Hamers, W. Lambert, L. Mononen, M. Seitz and R. Strack, 1978. Language Processing in Bilinguals. Brain and Language, 5, 1-12.

Greenberg, H. and J. Graham, 1970. Electroencephalic Changes During the Learning of Speech and Non-Speech Stimuli. Journal of Verbal Learning and Verbal Behavior, 9, 274-286.

Kimura, D., 1967. Functional Asymmetry of the Brain in Dichotic Listening. Cortex, 3, 163-178.

Matsumya, Y., V. Tagliasco, C. Lombroso, and H. Goodglass, 1972. Auditory Evoked Responses: Meaningfulness of Stimuli and Interhemispheric Asymmetry. Science, 175, 790-792.

Mononen, L. and M. Seitz, 1977. An AER Analysis of Contralateral Advantage In the Transmission of Auditory Information. Neuropsychologica, 15, 165-173.

Morrell, L. and J. Salamy, 1972. Hemispheric Asymmetry of Electrocortical Responses to Speech Stimuli. Science, 172, 588-600.

Picton, T. and R. Hink, 1974. Evoked Potentials: How? What? and Why? American Journal of EEG Technology, 14, 9-44.

Seitz, M., 1972. Behavioural and Electrophysiological Indicators of the Perception of Clicks Superimposed on Sentences. Ph.D. Dissertation, University of Washington, Seattle, Washington.

Seitz, M. and B. Weber, 1972. Left Hemisphere Processing of Clicks Related to Linguistic Function. A.S.H.A., 9.

Seitz, M, 1976. Effects of Response Requirements and Linguistic Contexts on AERs to Clicks Human Communication 1, Summer.

Shenker, R. and M. Seitz (in progress). Stuttering Behavior and Cerebral Asymmetry. Ph.D. dissertation, McGill University.

Wood, C., W. Goff and R. Day, 1970. Auditory Evoked Potentials During Speech Perception. Science, 173, 1243-1251.