Measuring Electrical Activity of the Brain

DAVID B. CHORLIAN, M.S., BERNICE PORJESZ, PH.D., AND HOWARD L. COHEN, PH.D.

The recording of brain electrical activity from scalp electrodes provides a noninvasive, sensitive measure of brain function (e.g., cognition). These electrical recordings consist of two phenomena: the continuous electroencephalogram (EEG) and timepoint-specific event-related brain potentials (ERP's). Unlike positron emission tomography (PET) or magnetic resonance imaging (MRI) techniques, brain mapping does not construct an image of a hidden anatomical structure; rather, it illustrates spatiotemporal brain activity (i.e., brain activity as it occurs in both space and time). This article presents a variety of brain mapping techniques, focusing on the ERP component P300.

RECORDING BRAIN ELECTRICAL ACTIVITY

The EEG is not linked in time to any specific event but instead reflects the activation level of various brain regions. For example, a person in a relaxed state will manifest a great deal of simultaneous brain wave activity occurring at a wave frequency between 8 and 12 cycles per second. Conversely, ERP's represent brain electrical activity in
response to specific sensory or cognitive events occurring at a specific time. In addition, ERP's consist of characteristic, highly reproducible wave forms that can be measured to within a fraction of a second, providing an immediate record of the brain activity associated with information processing. Because ERP signals are small and are embedded in the ongoing EEG, statistical techniques are used to extract them from the background EEG.

Depending on experimental conditions, ERP's may represent overlapping activity of many brain circuits. Therefore, they are useful in studying complex brain functions, such as sensory and information processing (e.g., memory). ERP's offer a unique approach for assessing brain function because they allow scientists to observe simultaneously electrical activity (i.e., electrophysiology) and cognition.

**How Are ERP's Obtained?**

To record ERP's, subjects wear a cap embedded with from 20 to 128 noninvasive scalp electrodes. ERP's can be measured in response to stimuli from any sensory modality (e.g., sight or sound) and also may be recorded while a behavioral task is being conducted. For example, ERP's can be obtained for visual stimuli using a method in which shapes or letters are presented on a computer screen while the subject performs a simple cognitive task, such as recognizing a particular shape. The subject may be asked to make a behavioral response (e.g., press a button whenever a particular shape appears) or keep count of how many specific stimuli have been presented. Scalp signals reflecting brain electrical activity are recorded simultaneously from the subject's scalp.

**What Does ERP's Reveal?**

The peak amplitudes of ERP's (i.e., negative and positive components, respectively) are also known as the N1 and P3 components. These components are measured from their peaks, as well as their latencies (i.e., difference of time between measurement and stimulus). The negative component is typically recorded following the N1 component (with a latency of about 200 ms), and the latter is known as the P3 component. The latencies of the N1 and P3 components are also influenced by the subject's task.

**Changes in Electrical Potential (µV)**

Much attention is focused on the positive component of the ERP, termed the P300 component, which is recorded following the N1 component. The latency of P300 is typically around 500 ms and is associated with a rear (i.e., parietal) scalp potential.

**What is P300?**

P300 is a positive wave form that is typically observed following a visual or auditory stimulus. It is thought to reflect the subject's cognitive processing of the stimulus, and it is often used as a measure of cognitive function in neuropsychological assessment.
ERP's reflect subtle, dynamic, real-time, millisecond-to-millisecond transactions that are elicited while the brain is challenged and are therefore highly sensitive to specific brain processes. Most sensory activity occurs within 100 ms after a stimulus is presented, and most cognitive activity takes place within 500 ms. Although images obtained using PET also offer a functional measure of brain processes, electrophysiological measures link images of brain activity to specific timepoints (i.e., provide a temporal resolution) with a precision far greater than that of PET's. Other imaging methods, such as MRI and computed tomography (CT) scans, portray gross brain structure but do not reflect ongoing electrical activity. Thus, they cannot provide direct measures of brain function. ERP abnormalities, however, can be observed even when MRI and CT images reveal no anatomical changes. In addition, many EEG and ERP characteristics are extremely sensitive to acute and chronic effects of alcohol on the brain and are responsive to intoxication, tolerance, withdrawal, and the effects of prolonged abstinence.

Electrophysiological features also may be hereditary markers of risk for alcoholism. Evidence indicates that the characteristics of both EEG's and ERP's are genetically determined and that P300 attributes generally differ between alcoholics and non-alcoholics (Porjesz and Begleiter 1995). A recent twin study (O'Connor et al. 1994)

---

**What Is a P300?**

Much attention has focused on the P300 component of the ERP, a prominent positive component peaking between 300 and 500 ms after a stimulus. Scalp recordings of P300 are strongest at the parietal area, a rear (i.e., posterior) brain region. The ERP task most commonly used to elicit the P300 is the so-called "oddball" task, in which subjects are asked to attend to and/or respond to a rare stimulus presented in a series of other stimuli. For example, in an auditory paradigm, the subject listens to frequent "boops" and rare "beeps" (targets) in a random stream of tone bursts presented about 1.5 seconds apart. The subject may be asked to press a button or count each time a target occurs (for a review, see Regan 1989). P300 results from auditory paradigms, however, are not as consistent as those from visual paradigms. Consequently, the P300 data discussed here are from a study using a visual paradigm in which alcoholics, high-risk subjects, and control subjects pressed a button in response to the rare occurrence of the target letter "X" embedded in a sequence of other visual shapes.

**Advantages of ERP Measurement in Alcoholism Research**

ERP's provide sensitive measures of brain functions. Unlike other imaging techniques, ERP's reflect subtle, dynamic, real-time, millisecond-to-millisecond transactions that are elicited while the brain is challenged and are therefore highly sensitive to specific brain processes. Most sensory activity occurs within 100 ms after a stimulus is presented, and most cognitive activity takes place within 500 ms. Although images obtained using PET also offer a functional measure of brain processes, electrophysiological measures link images of brain activity to specific timepoints (i.e., provide a temporal resolution) with a precision far greater than that of PET's. Other imaging methods, such as MRI and computed tomography (CT) scans, portray gross brain structure but do not reflect ongoing electrical activity. Thus, they cannot provide direct measures of brain function. ERP abnormalities, however, can be observed even when MRI and CT images reveal no anatomical changes. In addition, many EEG and ERP characteristics are extremely sensitive to acute and chronic effects of alcohol on the brain and are responsive to intoxication, tolerance, withdrawal, and the effects of prolonged abstinence.

Electrophysiological features also may be hereditary markers of risk for alcoholism. Evidence indicates that the characteristics of both EEG's and ERP's are genetically determined and that P300 attributes generally differ between alcoholics and non-alcoholics (Porjesz and Begleiter 1995). A recent twin study (O'Connor et al. 1994)
reported that P300 amplitude is highly heritable; similar findings on the heritability of P300 are being obtained by researchers in the Collaborative Study on the Genetics of Alcoholism (COGA) through a large family study (Porjesz et al. in press).

**METHODS OF ERP ANALYSIS AND MAPPING**

**Amplitude and Latency Measures**

Researchers have used various auditory and visual paradigms to study the P300 component and have found the P300 amplitude to be smaller in alcoholic subjects than in control subjects (figure 1) (for a review, see Porjesz and Begleiter 1993). Researchers previously thought that these low P300 voltages resulted from neurotoxic effects of alcohol on the brain. Low P300's, however, do not recover with prolonged abstinence and can occur in subjects at risk for alcoholism prior to alcohol exposure. Thus, low P300 amplitudes may characterize populations at risk for developing alcoholism (Polich et al. 1994).

**Topographic Representations**

Although amplitude and latency measures provide important information about brain function, they do not address the spatial distribution of ERP's across the scalp. Spatial distributions provide information about brain areas possibly involved in generating ERP activity. Displaying ERP's from multiple electrodes does not show values across the entire scalp surface but only at the sites of the electrodes. Mathematical techniques enable researchers to assign values to the points that have not been directly measured; maps can then be created by calculating the values between electrode points. Figures 2 and 3 show two types of maps—spatiotemporal and topographic—based on this approach (Fein et al. 1992).

Topographic maps are frozen at a single point in time, thereby losing the dynamic aspect of the recorded data. With the advent of computer technology, these spatial maps can be presented as a series of rapidly changing, computer-generated animations that describe how the topographic distribution of the recorded activity changes over time.

**MAPPING OF CURRENT SOURCE DENSITY**

Because voltages measured at a point on the scalp result from both local (i.e., directly under the electrode) and remote sources by mathematically transforming the ERP data, researchers can emphasize local sources. The data transformation produces a quantity known as the current source density (CSD), which represents the radially oriented current density at a point on the scalp. The CSD values denote current sources and "sinks" (i.e., locations where the current becomes undetectable). Researchers create CSD maps by taking simultaneous data from all the electrodes and converting them into spatial data. A CSD topographic map or spatiotemporal map (figures 4 and 5) may display results in a more useful fashion than a topographic map based on ERP's (figures 2 and 3).

In the P300 experiment mentioned earlier, for example, the peak of the P300 component (occurring at 430 ms) from 61 scalp electrodes is transformed to CSD. In healthy control subjects, these maps indicate a large posterior focus of activity as well as frontal (i.e., anterior) foci (figure 4). These brain-mapping techniques aid in pinpointing possible sites of brain dysfunction in alcoholics and in subjects at risk for developing alcoholism.

A comparison of CSD maps obtained from alcoholics and nonalcoholics shows weaker activity in the alcoholics' brains. Figure 5 displays the distribution of P300 activity across the alcoholics' scalps. Compared with control subjects, alcoholics can appear to have a weaker posterior focus of activity and no clear frontal focus. Therefore, control subjects and alcoholics exhibit not only differences in amplitude but differences in spatial distributions, particularly in the brain's frontal regions.
A more elaborate analysis of the electrophysiological data measures information communication from one location in the cerebral cortex to another. If a temporal pattern of electrical activity at one electrode matches the pattern at another electrode a few milliseconds later, information is likely being transferred from the first to the second location. Gevins and colleagues (1990) developed a mathematical method of examining time-lagged CSD data while a subject simultaneously...
performs a task. The results are interpreted as reflecting the activity of active networks in the cerebral cortex and can be applied to various ERP paradigms.

**Structural Findings**

To determine the relationship between brain structure and function, researchers have investigated the neuroanatomical origins of P300 using various techniques. Evidence from recordings obtained from electrodes implanted in the human brain implicates both the medial temporal lobe and the dorsal visual stream as reflecting the activity of specific brain networks. Electrophysiological brain mapping is performed as a window into the brain's function and in identifying people at risk for developing alcoholism. In contrast, conventional imaging techniques have helped identify brain structural changes resulting from alcoholism. Electrophysiological brain mapping is the representation of brain function in its spatiotemporal dimensions. These electrophysiological techniques provide exquisite temporal resolution of brain processes and have now been enhanced to provide spatial information about possible brain generators of this activity. These novel techniques not only provide a framework for understanding alcohol consumption on the brain and people who may be at risk for alcoholism.

**ACKNOWLEDGMENT**

The authors would like to thank Douglas Harsh for developing computer graphics software to create brain images.

**REFERENCES**

Fein, G.; Raz, J.; and Turetsky, B. Brain electrical activity: The promise of new technologies. In: Zakhari, S., and Witt, E., eds. Imaging in Alcohol Research. National Institute on Alcohol Abuse and Alcoholism Research Monograph No. 21. DHHS Publication No. (ADM)82-1890. Bethesda, MD: the Institute, 1992. pp. 49–78.

Ford, J.M.; Sullivan, L.M.; White, P.M.; Lim, K.O.; and Pettersson, A. The relationship between P500 amplitude and regional gray matter volumes depends upon the regional system engaged. **Electroencephalography and Clinical Neurophysiology** 90:214–228, 1994.

Greens, A.S.; Brelsford, S.L.; Cutillo, B.A.; Iles, J.; Miller, J.C.; Stein, J.; and Jex, H.R. Effects of prolonged mental work on functional brain topography. **Electroencephalography and Clinical Neurophysiology** 76:339–359, 1990.

O'Connor, S.J.; Moghadam, S.; Christian, J.C.; and Lu, Y.C. Heritable features of the auditory oddball event-related potential: Peaks, latencies, morphology and topography. **Electroencephalography and Clinical Neurophysiology** 92:115–125, 1994.

Oscar-Berman, M., and Hutner, N. Frontal lobe changes after chronic alcohol ingestion. In: Hunt, W.A., and Nixon, S.J., eds. Alcohol-Induced Brain Damage. National Institute on Alcohol Abuse and Alcoholism Research Monograph No. 22. NIH Publication No. 93-3549. Bethesda, MD: the Institute, 1993. pp. 121–167.

Porjesz, B.; Pollock, V.E.; and Bloom, F.E. Meta-analysis of P300 amplitude from males at risk for alcoholism. **Psychological Bulletin** 115:55–73, 1994.

Porjesz, B., and Begleiter, H. Neurophysiological factors associated with alcoholism. Hunt, W.A., and Nixon, S.J., eds. Alcohol-Induced Brain Damage. National Institute on Alcohol Abuse and Alcoholism Research Monograph No. 22. NIH Publication No. 93-3549. Bethesda, MD: the Institute, 1993. pp. 89–120.

Porjesz, B., and Begleiter, H. Event-related potentials and cognitive function in alcoholism. **Alcohol Health & Research World** 19(3):108–112, 1995.

Porjesz, B.; Begleiter, H.; Litte, A.; Bauer, L.O.; Kuperman, S.; O'Connor, S.J.; and Rohrbaugh, J. Visual P5 as a potential phenotypic marker for alcoholism: Evidence from the COGA national project. In: Ogura, C.; Koga, Y.; and Shimokochi, M., eds. Recent Advances in Event-Related Brain Potential Research. Amsterdam: Elsevier Science. in press.

Regan, D. Human Brain Electrophysiology: Evoked Potentials and Evoked Magnetic Fields in Science and Medicine. New York: Elsevier, 1989. pp. 236–245.

**CONCLUSIONS**

Electrophysiological recordings of ERP's reflect the activation of neural circuits involved in the mediation of sensory and cognitive processes. The assessment of ERP's has proven extremely useful in studying the effects of alcoholism on brain function and in identifying people at risk for developing alcoholism. In contrast, conventional imaging techniques have helped identify brain structural changes resulting from alcoholism. Electrophysiological brain mapping is the representation of brain function in its spatiotemporal dimensions. These electrophysiological techniques provide exquisite temporal resolution of brain processes and have now been enhanced to provide spatial information about possible brain generators of this activity. These novel techniques not only provide a window into the brain's function but also may contribute simple clinical tools for identifying both the adverse effects of alcohol consumption on the brain and people who may be at risk for alcoholism.