SESSION IV USING THREE-DIMENSIONAL GRAPHICS IN PSYCHOLOGY RESEARCH

Michael Yost, *Presider*

Using three-dimensional graphics in neuropsychological hypothesis testing

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This paper presents the application of an overlapping sampling technique used with a fast Fourier transform on electroencephalographic data. The use of this sampling and analysis technique is demonstrated on data in which steady state, rate of change, and critical event hypotheses are tested. The benefit of applying computer-generated three-dimensional graphics to the results of using this innovative sampling and analysis technique is emphasized.

We determined several years ago that there was an inordinate amount of variance in electroencephalographic (EEG) data (Bremner, Yost, & McKenzie, 1982). Although we believed that the data were gathered using valid techniques, we suspected that the large variances were a function of large inter- and intrasubject differences. We determined that there were large variances in the data gathered on a subject under a given experimental condition and that, when the data gathered on a set of 20 subjects under the same experimental condition were composited in a statistical analysis, the variance for the group more than doubled. Even though the differences in the means of two different groups of subjects under two different experimental conditions were "large," the variances kept us from obtaining statistically significant differences when we believed that the subjects' reactions to the different experimental conditions were significantly different. We were unsuccessful in overcoming the problem of large variances using different univariate, multivariate, and nonparametric techniques. Also, after examining several different methods of compositing and transforming data, we determined that each of these tended

to remove some of the information that was contained in the original data.

We solved the problem of large variances by developing a single-subject experimental design and statistical analysis approach for our research (Bremner, Yost, and Pike, 1984; Bremner, Yost, and Zintgraff, 1985; Yost, Bremner, & Fox, 1985). This approach permitted us to gather data in which the variance was the variation in the response of a single subject under a given experimental condition. When we made comparisons of responses to different experimental conditions, the variances were a function of differences in the response of a subject and not differences among subjects. Using these approaches, we were able to reduce the variances and obtain what we considered to be valid and reliable experimental results.

The fast Fourier transform (FFT) and a variety of smoothing functions are used in analyzing neuropsychological data. We examined the effect of these techniques in two studies (Yost, Bremner, Helmer, and Chino, 1986; Yost, Cooper, & Bremner, 1983). One of the major conclusions of these studies was that the results obtained from the FFT of EEG data are influenced by where in the data the FFT is initiated. Moving the starting point for the FFT analysis by as little as 16 data points (where a 256-sample-per-second sampling rate is used) can have an effect on

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the power obtained in 1-Hz spectral windows. Obviously, this can add unwanted and unexpected variance to an analysis. To determine how to cope with this problem, we examined other statistical analyses that might be used. We were unable to find or develop a new technique that would overcome the problem with FFT. Instead, we developed a new sampling technique that we use in conjunction with the FFT, which we believe gives a more precise representation of the data that are being analyzed. We refer to this technique as a *redundant FFT* (RFFT) (Yost, Bremner, & Strauss, 1987).

In a traditional FFT, data are divided into 1-sec segments and the FFTs are calculated in 1-sec data segments. In an RFFT, we begin by taking the data for the 1st sec and performing a FFT. Once the data for the 1st sec are analyzed, a computer program moves $\frac{1}{4}$ -sec (64 data points, assuming an A/D sampling rate of 256 per second) through the data, takes another 1-sec sample of data, and performs the next FFT. This process continues until the end of the data set is encountered. This process is analogous to taking a 1-sec window, sliding the window along the vector of data in $\frac{1}{4}$ -sec steps, and analyzing each successive, overlapping second. When this sampling technique is used in conjunction with a FFT, the differences in the power spectra that arise from entering the data set at some arbitrarily selected point and analyzing 1-sec data segments are reduced.

The data generated by the RFFT appear in a variable $\times$ time matrix. Typically, the variables are 1-Hz power spectra windows with the rows representing $\frac{1}{4}$ -sec (64 data points) time intervals. The matrix for a 20-sec EEG data segment, for example, contains 77 rows $[(19 \times 4) + 1]$. We do not analyze all of the windows of the power spectra, but we typically output the data for 3 through 12 Hz. There is nothing magical about using $\frac{1}{4}$ -sec increments in the sampling. We have used both larger and smaller increments and found that smaller increments generate an excessive amount of data without adding additional information, whereas larger increments do not add or carry enough information.

We are seldom interested in the data for only one 1-Hz spectral window. To evaluate the effect of a particular experimental condition, we usually analyze the data for at least three 1-Hz windows and at times as many as 10 such windows. Since the RFFT does not reduce the data to the same limited set as does the FFT, this requires us to analyze and display a great deal of data for each subject, especially when we use as many as four electrodes and gather data under as many as five experimental conditions.

The initial step in our studies is to examine the digitized data. In the past, this has been done by developing a two-dimensional (x, y) graph of the data. However, when multiple spectral windows are used, we find it very difficult to adequately examine the data in this type of graph. On the other hand, we find that by using a three-dimensional topographic-type graph, the data are relatively easy to analyze.

TYPES OF HYPOTHESES

Investigators in neuropsychological research work with three basic types of hypotheses. The first type can be referred to as *steady state hypotheses* (Eddy & Moise, 1985). These are hypotheses in which the investigator submits a subject (or subjects) to one or more experimental conditions in which the subject is, in general, expected to react in the same way throughout the time in which the stimulus is being delivered. An example of this type of study is one in which data are gathered while a subject is meditating. This type of hypothesis is frequently used in test-retest and $A \times B$ types of experimental designs.

The second type of hypothesis is what we refer to as the *rate of change hypothesis*. This is a hypothesis in which the subject's response to a stimulus changes at some definite rate as a stimulus is changed (Gevins, Doyle, Schaffer, & Callaway, 1980). Examples of this type of hypothesis are ones in which subjects respond to one or more computer-generated stimuli that are designed to change at some preset rate.

The third type of hypothesis is the *critical event hypothesis*. The designs employing this type of hypothesis are ones in which a stimulus is delivered to a subject until, for some reason, the subject can no longer respond. An example of this type of study would be one in which the subject is put under extreme pressure and is required to respond until the subject reaches his/her physical limits and stops (Lewis, McGovern, Miller, Eddy, & Forster, 1987). The objective of such studies is to determine the conditions that cause a subject to fail. Now, let us examine how the RFFT and three-dimensional graphics can be used in analyzing data in each of these types of hypotheses.

Steady State Hypothesis

The data used as an example of the steady state hypothesis were gathered on a 40-year-old male subject. The preparation of the subject, the instrumentation, and the conditions under which the data were gathered were the same as those described by Yost et al. (1985). The two sets of data were obtained while the subject was meditating and responding to biofeedback and were from a left occipital electrode (O_1).

The data presented in Figure 1 are for biofeedback and those in Figure 2 are for meditation. Both figures are graphs of raw power data for 10 1-Hz spectral windows (3 through 12 Hz). The 1-Hz windows are represented on the x -, or horizontal, axis of the plane on which the graph rests. The y -axis, or the axis that appears to extend back along the edge of the horizontal plane on which the graph rests, represents the $\frac{1}{4}$ -sec increments of 20 sec of data. The z -axis, or the height above the plane, represents the power for each 1 Hz at each $\frac{1}{4}$ sec. Note how the data for biofeedback tend to be in the 4- to 6-Hz range, whereas the data for meditation are in the 8- to 13-Hz range. It is also interesting to note how the subject emitted data that were "spiked" and not consistent and smooth. This pattern was consistent across trials.

The data were gathered on a once-a-week basis over a 4-week period on a subject. The four data patterns obtained from this subject were identical or highly similar. Another subject was submitted to the same stimuli over repeated trials. Consistent patterns of power were obtained across trials on this subject, but the patterns for the first subject were not the same as those for the second subject. These findings support our earlier decision to move to single-subject research and statistical designs to reduce variance.

There are several aspects of steady state hypothesis data that have become evident as a result of working with three-dimensional graphs of the RFFT data. First, we have always followed reasonable procedures in waiting for a subject to come under stimulus control before starting to record data, and in visually examining the analog data before choosing the place to begin the FFT. In an operational sense, we have made a two-part assumption. We have assumed, first, that the subject was under stimulus control at the beginning of the data set and, second, that he/she was under stimulus control throughout the data gathering session. Using the RFFT and the three-dimensional graphics on these data, on data from earlier studies, and on data from other subjects, we found that it is not uncommon for subjects to come under stimulus control after the start of the data set, for subjects to "take breaks" from the stimulus while data are being gathered, and for subjects to leave stimulus control (without the knowledge of the experimenter) prior to the end of a data gathering session. Obviously, breaks or inconsistencies in the data have contributed to what we and others have experienced as large variances. Also, this evidence makes the degree to which the data represent the reaction of a subject to a given stimulus questionable. The frequent, overlapping sampling employed by the RFFT in conjunction with the three-dimensional graphics permits us to clearly identify these phenomena.

We are currently considering analyzing the portion of data sets in which the subjects appear to be coming under

Figure 1. Biofeedback. Graph of raw power data for 10 1-Hz spectral windows (3-12 Hz). Example of steady state hypothesis.

Figure 2. Meditation. Graph of raw power data for 10 1-Hz spectral windows (3-12 Hz). Example of steady state hypothesis.

stimulus control. It is clear from initial observations that a subject appears to emit a relatively consistent pattern of powers at selected frequencies as he/she comes under stimulus control. However, these patterns appear for a very short duration. We plan to increase the overlap in sampling in the RFFT to analyze this portion of the data.

In testing steady state hypotheses, investigators analyze the data for a given frequency or frequencies. On the most part, investigators assume that the power output at these frequencies is consistent throughout the data set. Using the RFFT and three-dimensional graphics, we have identified a consistent trend in the data of a number of subjects under several experimental conditions, which makes us believe that it is not safe to make this assumption. It is common for a subject to emit almost no power at a particular 1-Hz window at the beginning of a data gathering session, and for the power at this frequency to grow steadily and become one of the dominant frequencies at the end of the session. This is frequently accompanied by the reverse of this trend in one or more adjacent frequencies. We refer to this as *frequency drift*. The consistency with which this occurs for different subjects under different stimuli leads us to believe that it is a real response of the subjects and not an artifact of the data. However, this phenomenon does add to the variance of the data. Identification of this phenomenon also adds to the validity of adding together the power of several adjacent 1-Hz frequency bands prior to statistical analyses. Under some circumstances, adding together the power at several adjacent frequencies does yield a more stable (less variant) measure.

Rate of Change Hypothesis

The data used as an example of the rate of change hypothesis were a representative sample gathered on a 40-year-old male subject. The preparation of the subject, the instrumentation, and the conditions under which the data were gathered were similar to those described by McKenzie, Bremner, and Eddy (1981). The data presented here were from an electrode placed at (O₁). The subject was

experienced at completing the Perelli task (Perelli, 1980a, 1980b) and was performing this task throughout the data gathering session. The Perelli task is a computer-driven cognitive task to which the subject responds by pushing buttons. At the beginning of the task, the subject is not hurried and is required to make simple responses. As the session progresses, the system requires more complex responses in less time. This continues until the subject can no longer correctly respond. At this point, the system starts again at the simplistic level. Figure 3 contains 30 sec of data in which the subject completed slightly more than two cycles of the task. The data presented in Figure 3 were sampled so that the beginning of the test was at the zero point on the y-axis. The beginning and end points of the task are apparent on the graph, and these points are consistent with the observed delivery of the stimulus to the subject. Note how there is an increase in power within a trial. Prior to the use of the RFFT and three-dimensional graphics, we used a nonoverlapping, 1-sec sampling technique. Using this approach, we were not able to clearly identify the rate of change in the subject's responses and precisely when he/she completed this task.

Critical Event Hypothesis

The data used as an example of testing the critical event hypothesis were gathered on a young (approximately 25-year-old) male subject. The data were collected from a single electrode placed at O_1 . The subject was seated in a human centrifuge and instrumented. While he completed a button-pushing cognitive task, he was accelerated until he lost consciousness. Body electrodes and a television camera were used to monitor the physical condition of the subject. In this study, Lewis et al. (1987) examined the response of the subject to the acceleration and the loss of consciousness. The objective of this study was to determine whether or not there was brain activity that would accompany the loss of consciousness (the critical event). Figure 4 is a graph containing 30 sec of data. Because of computer program and publication space limitations, we are displaying only the second 30 sec of the data. It is clear that there was very little more than a broad background of brain activity leading to the burst of activity

Figure 3. Perelli Task. Thirty seconds of data sampled so that beginning of test was zero point on the y-axis. Example of rate of change hypothesis.

Figure 4. Loss of Consciousness. Thirty seconds of data as an example of data testing the critical event hypothesis.

associated with the loss of consciousness. Because of the amplitude of the burst of activity, the broad background activity cannot be seen in the figure. We knew from the monitoring information exactly when the subject lost consciousness. When we compared the spectral data in the graph of the other sources of data, we found that the brain activity preceded the loss of consciousness by a portion of a second. In this case, as in the proceeding analysis, it would be impossible to identify when the critical event began if we were not using the sampling technique employed in the RFFT.

COMPUTERS AND THREE-DIMENSIONAL GRAPHICS

There are three-dimensional graphics programs that operate on relatively simple personal computers (PCs) and other single-purpose or dedicated computers. The dedicated computers are expensive and, as a result, are not widely used in psychological research. Three-dimensional graphics programs for PCs are becoming readily available at reasonable prices. They are currently available for use on IBM (and clones) and Macintosh computers. Most of these programs were developed to be used in conjunction with engineering-oriented Computer Aided Design (CAD) and with geologically oriented topographic maps. These computer programs typically require large amounts of memory and, because of their complexity, execute these programs very slowly. Therefore, it is very helpful to use a PC with a large memory capacity and a fast execution clock when doing three-dimensional graphics. The three-dimensional graphics discussed in this paper were generated with a computer program entitled *Energraphics* (Enertronics, 1985). There are several characteristics of three-dimensional graphics programs that enhance the analysis capabilities of an investigator.

First, once the data have been entered, it is possible to rotate the data around each of two perpendicular axes. That is, an investigator can view the data either on screen or in hard copy from any viewing angle that he/she might like. This permits viewing the data from a row perspec-

tive, a column perspective, or any angle. This feature can be very helpful when analyzing complex data.

Second, computer programs permit an investigator to remove all hidden lines from a graph. All figures in this paper have hidden lines removed. This feature permits an investigator to remove all secondary lines so that only the surface features of the data appear on the graph. This feature makes it easier to interpret the data. Some of the newer computer programs that employ high-resolution color graphics also employ shading and coloring of the three-dimensional surfaces to assist in interpretation of data.

The scaling coefficients feature of the computer programs is one that we use most frequently. The computer program contains a scaling coefficient for each of the three dimensions of the program. These coefficients permit an investigator to automatically expand or contract any or all of the three dimensions of the graph. Selected increases in the coefficients permit an investigator to zoom in on a portion of a graph to examine portions of it more closely. The most important use of these coefficients comes into play after a graph is brought up on the screen, scaled appropriately on the x - and y -axes, and viewed from a "good" angle. At this time, an investigator can use the scaling coefficient for the z -axis (the power) to determine what happens when different power ratios are used. When the coefficient for the z -axis is reduced, the smaller powers tend to be flattened out in the graph, and it becomes easier to view the dominant frequencies against a relatively flat background. When the coefficient is increased, it becomes easier to view the patterns in the lower power range and to analyze them.

CONCLUSIONS

Investigators involved in neuropsychological research collect continuous analog data because it is the best and simplest method of gathering data in which they are interested. Once the data are collected, they are A/D converted so they can be analyzed. Traditionally, a 256-sample-per-second sampling rate is used in the A/D conversion process. This high sampling rate is used for mathematical purposes, but it is also used because of the rapid rate at which neurons in the brain are firing. Since neurons are firing at a high rate, we select a sampling rate that will permit us to analyze the neurophysiological traits that they represent. Traditionally, when we perform a FFT, we analyze the data for each successive second. This means that we analyze the data at a rate that is much less than the sampling rate that preceded it and much less than the rate at which the neurons of the brain are reacting to stimuli. The traditional sampling rate used with FFT is too infrequent to permit investigators to analyze data that require identification of precise events or particular phenomena within the data. The overlapping sampling rate

used with the RFFT is designed to permit a more precise analysis of data and to enable us to test complex hypotheses.

When used in conjunction with the RFFT in single-subject experimental designs, three-dimensional graphics permit us to visually inspect and analyze data in ways that more traditional graphing techniques do not. The ability to display, rotate, smooth, and change the scales of data enhances the ability of an investigator to conduct neuropsychological research. Available, off-the-shelf computer programs that are designed for use in the physical sciences and that run on relatively simple PCs make the techniques available to almost any investigator.

REFERENCES

- BREMNER, F. J., YOST, M., & MCKENZIE, R. (1982). Computer-managed inferential statistical analysis of EEG data. *Behavior Research Methods & Instrumentation*, **14**, 300-302.
- BREMNER, F. J., YOST, M., & PIKE, A. A. (1984, April). *The reliability of the single subject statistics for biofeedback studies*. Presented to the Biofeedback Society of America.
- BREMNER, F. J., YOST, M., & ZINTGRAFF, C. (1985). Computer applications in single-subject research designs: A longitudinal study of cardiac component analysis. *Behavior Research Methods, Instruments, & Computers*, **17**, 319-322.
- EDDY, D. R., & MOISE, S. L. (1985). A comparison of single-subject and traditional statistical designs in steady-state evoked potential research. *Behavioral Research Methods, Instruments, & Computers*, **17**, 323-326.
- ENERTRONICS. (1985). *Energraphics* [Computer program]. Clayton, MO: Author.
- GEVINS, A. S., DOYLE, J. C., SCHAFER, R. E., & CALLAWAY, Y. C. (1980). Lateralized cognitive processes and the electroencephalogram. *Science*, **207**, 1006-1007.
- LEWIS, N. L., MCGOVERN, J. B., MILLER, J. C., EDDY, D. R., & FORSTER, E. M. (1987). EEG indices of G-induced loss of consciousness. In *Proceedings of Advisory Group for Aero-space Research and Development*. Oslo, Norway: North Atlantic Treaty Organization (NATO).
- MCKENZIE, R. E., BREMNER, F. J., & EDDY, D. E. (1981). *Determination of baseline psychophysiological parameters for visual, auditory, and tactile sensory modalities* (Report No. RF 3919-26). Washington, DC: United States Air Force.
- PERELLI, L. (1980a). *Effects of fatigue stressors on flying performance*. Unpublished doctoral dissertation, Catholic University of America, Washington, DC.
- PERELLI, L. (1980b). *Fatigue stressors in simulated long-duration flight* (Report No. SAM-TR-80-49). Brooks AFB, Texas: USAF School of Aerospace Medicine.
- YOST, M., BREMNER, F. J., & FOX, C. (1985, April). *Biofeedback: A longitudinal study on a single subject*. Paper presented at the meeting of the Biofeedback Society of America, New Orleans, LA.
- YOST, M., BREMNER, F. J., HELMER, R. J., & CHINO, M. C. (1986). The effect of smoothing functions on data obtained from a FFT. *Behavior Research Methods, Instruments, & Computers*, **18**, 263-266.
- YOST, M., BREMNER, F. J., & STRAUSS, R. (1987). Simulation of motor-neuronal networks. *Behavior Research Methods, Instruments, & Computers*, **19**, 113-116.
- YOST, M., COOPER, R., & BREMNER, F. J. (1983). Fourier analyses: A mathematical and geometric explanation. *Behavior Research Methods, Instruments, & Computers*, **15**, 258-261.