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PROBE-EVOKED EVENT-RELATED POTENTIAL TECHNIQUES
FOR EVALUATING ASPECTS
OF ATTENTION AND INFORMATION PROCESSING

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Probe event related potentials (Probe ERP) have been studied since the 1960s. In this context, a probe stimulus, by definition, is a stimulus irrelevant to task performance, which is introduced during task performance. The major premise underlying the use of probe ERPs is the belief that the ERP to such stimuli is significantly affected by task requirements. To the extent that the task and the probe stimulus share cerebral "space," one would hope that components of the probe ERP would be altered as a function of cerebral space being allocated to primary task performance.

Most of the recent literature dealing with probe ERPs has focused on the issue of hemispheric specialization. To the extent that one hemisphere is more utilized in the processing of a specific type of information, that hemisphere should demonstrate greater attenuation of probe ERPs than the less used hemisphere.

Earlier studies investigated more general questions, such as the effect of attention attracting visual stimuli on the ERP to light flashes. For example, Lehmann, Beeler, and Fender (1) and van Hof (2) report that when a patterned stimulus, as compared to a dark field or unpatterned stimulus, is presented to one eye, and flash stimuli to the other eye, the ERP to the flash stimuli is significantly affected. A structured target reduces the amplitude of the flash evoked response, as measured by the area under the ERP curve.

The major problem with many of the early studies was the lack of control for attentional variables. Could the described effects have simply been due to alterations in attention produced by the introduction of a task superimposed on the probe stimuli? The literature also is confusing, with respect to the nature of the response to probe stimuli. Some studies find augmentation; others, reduction; and still others, no effect as a function of primary task performance. Some studies report that early components of the ERPs are affected; others report late components are affected.

Since the mid-1970s, a number of laboratories have used probe ERP procedures to tap differential hemispheric processing. Galin and coworkers (3); Shucard and collaborators (4); and Papanicolaou and his collaborators (5) were some of the earliest investigators to utilize probe ERPs for the evaluation of differential hemispheric processing. The results of these investigations are generally supportive of hemispheric differences in information processing, as indexed by alterations in components of the probe ERP.

We will not review the results of these studies, but, in general, we concur with the critical comments made by Gevins and Schaffer (6) with respect to these and other studies purporting to demonstrate EEG correlates

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of higher cortical functions. The following quote from their (1980) paper will alert the reader to the caustic nature of their comments.

"In the ensuing 50 years (since Berger's discovery of the human EEG, in general, and the alpha rhythm, in particular), no clear understanding of the relationship between EEG patterns and higher cortical functions has developed, despite an ever-increasing sophistication in experimental and analytic procedures" (p. 113). We do not propose to either critique their comments or accept them, carte blanche.

Which of their comments are most appropriate, with respect to the evaluation of studies utilizing probe ERPs? Most such studies have subjects performing relatively complex tasks, such as solving arithmetic problems, assembling Kohs blocks, or reading. Probe stimuli are presented at either fixed or random time points, while subjects are engaged in these tasks. Fixed, here, means that they are presented at regular time intervals, and become predictable on that basis. They are not, however, fixed with respect to either primary task stimulus presentation or task processing requirements. Random presentation, here, simply refers to temporal randomness, with respect to primary stimulus presentation. Many of these studies have concerned themselves with differences in these probe ERPs between bilaterally symmetrical skull sites, with the assumption that certain tasks principally tap the functions attributable to one hemisphere, while other tasks are more demanding of the other hemisphere. It is the contention of Gevins and Schaffer that there are no tasks which truly differentially tap the two hemispheres, and that the performance of any task involves dynamic processes that are not restricted to one or the other hemisphere. Gevins et al. (7, 8) present data that even simple perceptual tasks involving spatial judgment and visuomotor integration, produce complex patterns of cortical activity with shifts not only between hemispheres, but also within a hemisphere. These are, truly, variable spatio-temporal events.

During this complex interplay between various cortical and subcortical sites, we now introduce probe stimuli. These come at essentially random time points during such information processing. How can they possibly provide us with much coherent information? The answer is that, for every published study which has obtained positive results, there is at least one published study with negative results, as well as untold studies with negative or inconclusive results.

We will briefly review the results of one study purporting to demonstrate laterality effects on probe ERPs attributable to differential processing of an arithmetic and a visuospatial processing task. We have not singled out this study, but have selected it randomly from those available to us (Papanikolaou, 5).

Probe stimuli, in this experiment, were 70 dB., 1000 Hz tones, presented at a rate of 1.3 per second, with 84% of the tones 50 msec in duration, and 16% of 60 msec duration.

The primary experimental task involved the visual presentation of a random shape, and a shape divided into three irregular sections. A number (between one and nine) was centered in each irregular section, as well as in the full random shape. For 84% of the trials, the three segments, when

joined, matched the random shape and the sum of the three numbers in the sections, when added together, matched the number in the full shape.

ERPs were recorded from the temporal and parietal areas on the left and right side (T_3, P_3, T_4, P_4), using linked ear reference. Under the control condition, subjects were required to gaze at the visual display, but attend to the tones and make a simple manual response to the 60 msec tone. In the two experimental conditions, the subject was required to either attend to the shapes or the numbers, and make the same simple, manual response to the "aberrant" stimulus set.

N1 (90 msec latency) - P2 (170 msec latency) amplitude difference was the component of interest. This measure was obtained for all three conditions, and a ratio of N1-P2 amplitude, with the control task as the denominator and the experimental tasks as the numerator ("arithmetic" and "visuospatial"), were calculated. The results were that this ratio was less than 1.0 for the visuospatial task, regardless of recording site, while there was some augmentation for the arithmetic task for P_3, P_4, and T_4. For P_3 and P_4, the augmentation was approximately 7%, while for T4, it was 15%. Using "t" tests to evaluate whether these ratios were significantly different from 0, none of the augmenting proved to be reliable. Significant attenuation was obtained at T_3 (10%, 15%) for both tasks, while significant attenuation was also found at P_3 (10%) and P_4 (25%) for the visuospatial task only. Attenuation for the visuospatial task was significantly greater at P_4, as compared to P3 and T3. These results, (ref. 5, p. 287, last paragraph) were interpreted as follows:

> These findings reaffirm the widely documented involvement of the left temporal area of dextral individuals in serial-analytic operations such as those required by the present arithmetic task. They also accord with the notion of predominant contribution of the right posterior region of the brain in visuospatial processing (e.g., see Hecaen & Albert, ref. 9). In addition, however, they indicate that the left, rather than the right, temporal area was involved in that task. At present, it is unclear whether this pattern of cerebral excitation, especially the involvement of the left temporal area, is representative of visuospatial processing at large, or confined to the specific task employed in this study. In this task, two alternative strategies could be used equally efficiently: The first would require mental segregation of the scattered sections and subsequent comparison of the resulting shape to the intact one. The second could simply involve comparison of each scattered section to the sections of the intact shape. Though both strategies require visuospatial processing, the latter does not entail mental manipulation of the visual stimuli and it does contain a serial-analytic component. Whether employment of this strategy accounts for the observed engagement of the left hemisphere in the present study, is a question deserving further exploration.

Our critique of this study focuses on two major issues, one dealing with: a) the logic of the specific control condition used, and b) the logic of introducing probes at 1.3 sec intervals during information acquisition processing and responding.

    a.   Why would one use a condition in which subjects are required to process information presented in the auditory mode as a control

for evaluating the ERP to that same stimulus condition, where the S is (attending to visually displayed information), not attending to the auditory information. Thus, perhaps a more reasonable control might have been a condition where everything was presented without any task demands.

b.   The logic of averaging across probe stimuli presented at four different points in time, with respect to primary task performance, is also suspect.

Since visual stimuli were presented for four seconds, and the auditory stimuli at 1.3 second intervals, one may infer that auditory stimuli were presented concurrent with visual stimulus onset, 1.3 and 2.6 seconds into the visual stimulus presentation period, and immediately preceding termination of that stimulus. Evoked responses to these stimuli were averaged.

If one conceives of the auditory discrimination, the arithmetic and the visuospatial tasks as information processing tasks, then what happens during the four second stimulus presentation period must differ from second to second, or millisecond to millisecond. For the auditory task, the presentation of the visual stimulus signals the onset of a series of four tones. Most of these tones (84%) are 50 msec in duration. The subject must discriminate between 50 and 60 msec duration stimuli and make a manual response to the 60 msec tone pip. This involves the development of an internal "model," for the shorter of the two stimuli, and deciding that the longer one does not match that model. (We suspect that the model should be for the shorter stimulus, because it is more frequently presented). Under these conditions, we would not expect any eye movements. This expectation has some empirical foundation, albeit utilizing stimuli of longer durations. For the arithmetic task, he may sequentially scan the three partial displays, abstract the numbers, add them together, and then look at the full display and compare that number with his addition, and make the appropriate response. For the visuospatial task, he probably scans back and forth between the segments and the full figure to make the decision. Thus, there is considerably more visual scanning activity in the latter task than in the arithmetic task, and more visual scanning in the arithmetic than the auditory discrimination task. One might also suspect that the time necessary to arrive at a decision might differ between the two (or even three) tasks, and that the timing of the motor response may affect the ERP.

We are, thus, surprised that significant results were obtained in this study. I am not surprised that the results were interpretable. One of man's unique abilities is the generation of hypotheses to account for any set of results. I can rationalize almost any set of data involving CNS activity, if you will allow me the concepts of excitation and inhibition.

In view of these rather negative and devastating comments, what is it that we did which we consider a marked improvement over the approaches taken by other researchers utilizing probe ERPs? It is our contention that probe ERPs have to be presented at points in time where one can be assured that more or less specific aspects of information intake or processing are occurring. Thus, we time-locked our probe ERPs to aspects of stimulus presentation. Such time-locking has been relatively crude, and can be improved upon in a number of ways.

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Before suggesting such improvements, I will review results of a study conducted in our laboratory utilizing such probe ERPs, as well as evaluating ERPs to primary task performance. These studies have also evaluated other physiological measures, specifically, heat rate (HR) and aspects of blinking (10).

We have modified the Sternberg memory paradigm to allow us to evaluate aspects of anticipation or expectancy, information acquisition and retention, or memory and comparison. First of all, our procedure provides the subject with information about the expected memory set (e.g., is it small or large; does it involve symbol set A or symbol set B). Second, since a fixed time is allowed to elapse between presentation of this CUE information and presentation of the MEMORY set, he also "knows" when the memory set presentation will occur. The CUE stimulus, thus, provides him with up to three units of information about the upcoming memory set, size, nature, and its time of arrival. The MEMORY set is then presented for a fixed time period, followed by a constant duration retention period. Following this, a TEST stimulus is presented, which is or is not a member of the set presented during the MEMORY period. The subject makes a discriminative response. After a fixed interval, the next CUE stimulus is presented. All information is visually presented and is under computer control. In addition to these information bearing stimuli, the subject is presented a probe stimulus, which occurs at one of six temporal locations--three between CUE and MEMORY sets, and three between the MEMORY and TEST stimuli. Probe stimuli occurred early in the middle, or immediately preceding presentation of the next stimulus. In the first experiment, early was defined as 1300 msec following stimulus offset, middle was 2500 msec after offset, and late was one second before presentation of the next stimulus.

We evaluated the ERPs to these probe stimuli, as well as the CUE, MEMORY, and TEST stimulus. With respect to the latter stimuli, what did we learn?

1. Knowing what to expect, whether it involved partial or full knowledge, leads to smaller P3 amplitude to the MEMORY stimuli, than not knowing what to expect. This effect is restricted to the anticipation of large set size only (Bauer, 1987, ref. 10) (Donchin, 1981, ref. 11) expected stimuli elicit smaller P3 than unexpected ones).

2. CUE and MEMORY stimulus produced ERP differences for P1, P2 and P3. P1 and P2 amplitudes are larger to the CUE stimulus; P3--amplitude is greater for MEMORY set.

3. With respect to the memory set, we find:

    a. P3 amplitude directly related to set size, with the larger set size generating larger P3's than the smaller set sizes (two studies).

    b. We found the P2 amplitude component of the ERP to the memory set significantly greater on the left side of the head (P_3) for English, as compared to Katakana characters. It was significantly greater on the right side of the heads (P_4) for Katakana characters.

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c. This effect occurs only under fully cued conditions. In other words, the laterality effect to the MEMORY set only occurs when subjects fully know what to expect (and can "prepare" to deal with the material).

4. To the TEST stimulus, we

a. corroborated both previous results from our and other laboratories, in that P3 amplitude is inversely related to set size. This effect is seen equally in left and right derivations.

b. found N2 amplitude to increase with set size on match trials only, and this only over the right hemisphere.

What results have we obtained from our probe ERPs, to date?

In our first study (Pz, Fz), we demonstrated that differential effects of set size were restricted to the probe which immediately preceded presentation of the MEMORY set and the probe immediately following the MEMORY set. Amplitude of the P1-N1 component increased with set size in anticipation of the MEMORY set and N1-P2 decreased with increasing set size immediately following memory set size presentation.

The "anticipatory" effect appears to be limited to midline lead placements, since it was not replicated in a study in which we recorded from parietal and temporal leads on the left and right sides.

For the MEMORY period (P), there was a significant probe position effect in the Bauer study, with both P1-N1 and N1-P2 increasing in amplitude, as one moved from the first to the third probe position, and a decrease in P2-N2.

Although I continue to have lingering doubts about the applicability of ERPs in simulation and real world environments, our studies, to date, have provided us with some landmarks suggesting both the utility of primary and probe stimuli on both probe and primary task elicited ERPs in the evaluation of "spare channel capacity."

My lingering doubts are not restricted to the application of the ERP to simulation and field condition, but to the laboratory situation, as well. Relatively minor changes in the experimental paradigm can produce major shifts in ERP findings. Whether this is interpreted as sensitivity of the ERP paradigm, or whether one attributes the ERP results to error variance, is a highly subjective matter.

A recently published study by Brumaghim and collaborators (1987, ref. 12) demonstrates such changes in ERP components nicely. They restricted their analyses to the P_{3b} component as affected by methyphenidate, and conducted two studies. In both studies, they found P3b latency affected by memory load, but in only one of the two studies was it affected by methylphenidate. To quote "The explanation of this effect, however, is not clear (p. 371). I suspect that everyone doing ERP research can come up with some examples of non-replicability of results from one study to another).

In spite of my doubts, how might one go about the task of using task elicited ERPs in the flight simulator. If, for example, we can take time of arrival of the eyes on a particular instrument as one variable of concern, and dwell time on the instrument as a second variable, one which reflects importance of the information displayed, one might look at ERPs triggered by saccade termination (the one which slews the eyes to the appropriate instrument) for fixation pauses of specified durations. One might go a step (or two) further, and look at patterns of ocular activity and associated ERPs.

If looking at instrument A is followed by looking at instrument B, assign the ERP to a different bin than if the second look is on instrument C, D, or E. It may well be that the importance of the information obtained from display A is greater, if followed by a glance at B, than any other location, and that the ERP to momentarily "important" display will be different from that elicited by a routine instrument check. With respect to probe ERPs, one could consider the introduction of such probes associated with the eyes falling on a particular display. Is the probe ERP to a display from which information is abstracted rapidly discriminable from one where such information abstraction is slow?

Thus, both primary stimulus, as well as probe ERPs, can be moved from the laboratory to the simulator, and to field conditions.

REFERENCES

1. Lehmann, D., Beeler, G.W. Jr., and Fender, D.H. EEG responses to light flashes during the observation of stabilized and normal retinal images. EEG and Clinical Neurophysiology, 1967, 22, 136-142.

2. van Hof, M.W. The relation between the cortical responses to flash and to flicker in man. Acto physiologica pharmacologia neederlander, 1960, 9, 210-240.

3. Galin, D. and Ellis, R.R. Asymmetry in evoked potential as an index of lateralization of cognitive processes: Relation to EEG alpha asymmetry. Neuropsychologia, 1975, 13, 45-50.

4. Shucard, S.W., Chucard, J.S. and Thomas, D.F. Auditory evoked potentials as probes of hemispheric differences in cognitive processing. Science, 1977, 212, 344-346.

5. Papanicolaou, A.C., Schmidt, A.L., Moor, B.D. and Eisenberg, H.M. Cerebral activation patterns in an arithmetic and visuospatial study processing task. International Journal of Neuroscience, 1983, 20, 283-288.

6. Gevins, A.S. and Schaffer, R.E. A critical review of EEG correlates of higher cortical functions. CRC Critical Review in Bioengineering, 1980, 113-164.

7. Gevins, A.S., Doyle, J.C., Cutillo, B.A. et al. Electrical potentials in human brain during cognition: New method reveals dynamic patterns of correlation. Science, 1981, 213, 918-922.

8. Gevins, A.S. Brain potential evidence for lateralization of higher cognitive functions. In J.P. Hellige (ed) Cerebral Hemisphere Asymmetry Praeger, 1983.

9. Hecan, H. and Albert, L.M. Human Neuropsychology, New York, Wiley, 1978.

10. Bauer, L.O., Goldstein, R. and Stern, J.A. Effects of information processing demands on physiological response patterns. Human Factors, 1987, 29.

11. Donchin, E. Surprise!... Surprise? Psychophysiology, 1981, 8, 493-513.

12. Brumaghim, J.T., Klorman, R., Strauss, J., Lewine, J.D. and Goldstein, M.G. Does methylphenidate affect information processing? Findings from two studies on performance and P3b latency. Psychophysiology, 1987, 24, 361-372.