PSYCHOPHYSIOLOGICAL MONITORING: POSSIBILITIES AND PROSPECTS

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1.0 INTRODUCTION

1.1 The use of psychophysiology in monitoring

1.1.1 The principal theme of the report

This report will describe for the present, near, and long term (10-20 years) the evolving capabilities for monitoring and interpreting psychophysiological signals and in particular the Event Related Brain Potential (ERP) with particular emphasis on such ERP components as the P300. Of special interest are the theoretical capabilities and constraints that will determine the utility of this field of science as the foundation for monitoring and inferring conclusions concerning office workers and workers in comparable environments.

1.1.2 Motivation for the report

Both technological and theoretical developments have greatly amplified the potential for, and the interest in, the use of psychophysiological signals as a means for monitoring cognitive and affective processes and responses in humans. Such monitoring is not novel. Inferences from psychophysiological signals are a routine matter in daily life. Whenever a companion's blush leads one to take one action rather than another a psychophysiological signal is used to monitor a human mind. The blush is an externally observed response of a bodily system and we know that there is a relatively stable relationship between a person's state of mind and the appearance and intensity of the blush. The use of the blush in this manner illustrates well the paradigm characterizing all the monitoring discussed in this report. It involves:

a. A means for making external observations on the activity of a bodily system.

b. A knowledge base that informs us about the relationship between the bodily system and cognitive and affective processes and responses. (This knowledge base may include statements that describe empirically determined correlations, e.g. "People blush when they are embarrassed." The knowledge base may be more theoretical, e.g. "Embarrassment causes system X to lead gland Y to secrete hormone Z. This hormone causes vasodilation.")

c. There exist rules, derived from the knowledge base, that allow inferences regarding psychological entities from observations of physiological function.

1.2 Factors that increased the power of monitoring

The power of this paradigm has been much amplified by the following developments:

The detection of the activity of bodily systems depends on the availability of systems that can be used to detect and record the signals.

This requires:

a. Sensitive transducers for transforming the chemical or the physical manifestations of the activity of bodily organs into electrical signals that can be recorded and analyzed.

b. A highly reliable signal conditioning and recording system whose noise level is lower than the necessary resolution of the signals.

c. Data acquisition and processing systems that can analyze in real time large masses of data.

d. A development of psychological theory that could supply the concepts and tools necessary to provide the psychophysiologist with a source of constructs and models.

e. Reliable observations on the empirical relationships between psychological and physiological observations.

f. A development of the theory, and the empirical observation, of the biological systems under observation.

It turns out that all of these conditions have been met by technological advances in the last couple of decades. These have increased the sensitivity of transducers and made it possible to record a much broader range of signals. This in turn has led to a tremendous expansion in the repertoire of measures available to the Psychophysiologist. The explosive development of Cognitive Psychology and of Neuroscience provided extended and very useful conceptual foundations for the field as well as a large body of data that can be integrated with the Psychophysiological data.

Thus, the range of phenomena that can be monitored and the strength of the inferences they permit is large and increasing. These capabilities focused the attention of developers on the possible applications of these monitoring technologies in a wide variety of domains. Applications range from the traditional use of Psychophysiology in clinical diagnosis through needs for monitoring that arise in various commercial and governmental domains. The most extensive application of ERPs has been made in medical diagnosis in particular in the assessment of sensory function (Halliday, 1982). A procedure that has assumed the status of a standard medical test utilizes ERPs with very short latencies known as the Brain Stem Evoked Potentials. These ERPs appear within 3-5 milliseconds of the occurrence of an auditory stimulus and they last for about 5 msec. It turns out that the appearance of these waves in a sequence and with timing that deviates from the normal is an excellent indication that the brain stem has been somehow damaged (Bodis-Wolner, 1982).

Medical applications are being developed also in more cognitive domains. These, however, are not yet in widespread use. It has been reported, for example, that a particular brain response (the P300) is markedly slowed in people sufferng Senile Dementia (Goodin, Squires and Starr, 1978). This prolongation may serve to distinguish patients suffering from depression from those who are senile. The literature on this application is of many opinions, (for a review see Donchin, Miller and Farwell, in press). However, it is likely that several such applications will emerge in the next decade (a review of the applications of ERPs in Psychiatric research is available in Pritchard, 1986). The main elements of these developments will be:

a. An expanding understanding of the neuroanatomical origin of the components is likely to emerge from studies of ERPs using indwelling electrodes in human patients (Allison, Wood, and McCarthy, 1986); from studies of ERPs in animals (Vaughan, 1982) and from studies of the neuromagnetic analog of the ERP (Okada, 1983).

b. An expanding understanding of the functional significance of the potentials is developing as studies of the ERP are conducted with increasing attention to theories and models of cognitive psychology. (Hillyard and Kutas, 1983; Galliard and Ritter, 1983; Donchin, 1984)

c. The decreasing costs of computing power and the increasing sophistication of graphic displays is making it possible for investigators to utilize much larger data bases than were possible in the immediate past. Thus, the study of multiple electrodes and the analysis and display of two, and even three dimensional, data patterns greatly increase the power of the analyses (see for example Morstyn, Duffy and McCarley, 1983).

Of course, the above examples derive from only one of the many psychophysiological techniques currently under intensive developments. The application of blood flow measurements, Magnetic Resonance Imagery and similar approaches allow a determination in vivo of patterns of brain activity with an increasing spatial and temporal resolution. All of these techniques share the property that they provide information on the degree to which a subset of brain regions is active at any given time. The activation is measured by assuring, using chemical labeling techniques, that brain activity would be manifested through the skull because the chemical, or the biophysical, label is detectable by extra cranial probes. These data are often analyzed by the methods of tomography to provide three dimensional images of considerable resolution. While currently available techniques have a temporal resolution measured in seconds it is likely that over the next decade the resolution will be improved substantially.

As will be seen below, the range of applications extends beyond medical diagnosis and monitoring. The applications in the area of Engineering Psychology, for example, are beginning to move from the laboratory to field testing. Thus, AFAMRL awarded in the early 80ies a substantial contract to the General Dynamics Corporation to test the feasibility of a Psychophysiological Battery developed at the Cognitive Psychophysiological Laboratory at the University of Illinois for the measurement of Mental Workload (See Heffley et al 1985; Otto et al, 1985; Gopher and Donchin, in press). The technological developments greatly reduced the cost and simplified the operation of the psychophysiological recording equipment. With the wide availability of such devices it is easy to see how they may get into hands less responsible than those found in the laboratory. The potential for abuse is substantial.

1.2.1 Plan of the report

This report will provide an overview of currently available Psychophysiological monitoring techniques. The general principles underlying these procedures will be sketched and illustrated, largely by reference to Interrogative Polygraphy, commonly known as Lie Detection, an unfortunate misnomer. We shall then focus on one class of Psychophysiological signals: the Event Related Brain Potentials (ERP). These will be introduced and their scope and range will be enumerated. The utility of one such component in monitoring studies will be described and future trends will be assessed. A discussion of the potential for commercialization, that would lack scientific basis, will be considered.

2.0 AN ILLUSTRATION OF PSYCHOPHYSIOLOGICAL MONITORING: "LIE DETECTION."

2.0.1 An overview of traditional polygraphy

It is useful to dwell briefly on one of the most common domains in which Psychophysiological signals are used for monitoring. This is the domain of "Lie Detection." Or, as we shall call it here, Interrogative Polygraphy (IP). All current approaches to IP are based on the assumption that a deceptive action on the part of the subject will be accompanied by an affective (i.e., emotional) reaction. The term "affective" rather than "emotional" will be used here because the term "emotion" is often used to include the perceived component of the reaction. However, subjects may react affectively to a situation without necessarily being aware of the fact. In other words, it is possible to react affectively without a concomitant emotional reaction . This reaction, in turn, is associated with activity in the Autonomic Nervous System (ANS, an activity that is manifested by an ensemble of actions generated within a variety of effectors driven by the ANS). Some of these actions can be detected by monitoring several organs whose activity is modulated by the ANS. The most commonly used ANS driven responses used in IP are the acceleration, or deceleration, of the heart rate; changes in the depth and the rate of respiration and the activity of sweat glands as manifested by the "Galvanic Skin Response."

The "Lie Detector" is a polygraph that is used to monitor these three responses. The Interrogator presents the subject with a sequence of events (words, questions, sentences, pictures and such like) and the degree to which an event elicits a response in one, or all, of the monitored responses is recorded. The pattern of ANS activity is then used to determine which, if any, of the stimuli elicited a supra threshold affective response. Different investigators tend to use different thresholds in detecting a response. There are also substantial differences in the method for developing and presenting the stimuli. However, in the main we can ignore these details and view the standard, ANS based, IP as an attempt to determine if the critical items do, or do not, elicit an affective response from the subject. In the more common technique the affective response to the items regarding which deception is under investigation are compared to the response to "control" items. The control items are questions that are not relevant to the subject of the investigation but which are likely to elicit an affective reaction. A question like "have you ever masturbated?" may serve as such a control question as it is assumed to elicit a defensive reaction in all subjects.

2.0.2 The character of Psychophysiological Monitoring

The nature of IP illustrates well some of the critical aspects of Polygraphy which must be kept in mind in assessing all forms of monitoring discussed in this report. The most important point is that the instrument used by the Polygrapher does not provide for the direct observation of a psychological process. Rather, the instrument measures a variety of organismic variables. The relationship to psychological variables is inferential and its validity is not assured by the reliability and validity with which the physiological functions are measured. The technical propriety of the measurement is a necessary but not a sufficient condition for the psychological validity of the measures.

A critical element in the interpretation of these measurements in the psychological domain is the situation in which the measurements are made. Any stimulus presented to the subjects is interpreted by that subject within the framework of the perceived situation and the ensemble of memories, expectations, and attitudes that are brought into the measurement environment. These psychological factors are inextricable from the technological aspects of the measurement. It is important to understand, in evaluating the technology, that its success does not depend solely on technological factors. The effectiveness with which the test environment is set up and the subject's participation in the creation of the psychological context will be critical (See Lykken, 1981).

2.1 Difficulties Associated with ANS-Based IP

In this section we review a number of the problems presented by the application of psychophysiological measurements in IP as an illustration of psychophysiological monitoring.

2.1.1 Introduction

While the use of affective responses in the detection of deception has many advocates and the technique is widely employed by government agencies and by private practitioners, it suffers a number of inherent difficulties. In any detection procedure the utility depends in part on the ratio of False Negatives to False Positives yielded by the technique and in the behavior of this ratio as a function of changes in the decision criterion. I will ignore, in this discussion, the difficulties encountered in validating IP that derive from the paucity of independently verifiable criteria for the deceptiveness or verifiability of the subjects. This matter has been discussed in great detail by protagonists of the Polygraphy debate such as Lykken and Raskin; for an accurate and accessible review of the issues see Ekman (1985). I will also ignore, for the moment, the sensitivity of the test to the arousal level of the individual. Let me just enumerate briefly some of the features inherent in the use of affective responses as indicators of a specific emotion and as specific indicators of deception.

2.1.2 The Non-Specific Nature of ANS Activity

Perhaps most serious is the relatively non-specific nature of affective responses. This non-specificity is double-barreled. It operates at the level of defining the direction and cognitive content of the emotion and it operates at the level of manifestation of the affect via ANS activity.

The difficulty in inferring emotions from their ANS "correlates" is well known. As has been reported in many studies of IP, False Positives are often the consequence of an affective response to a question, or to the presentation of an item, for reasons that have little or nothing to do with deception. Conversely, False Negatives often result from the absence, or the low amplitude, of an ANS manifestation of an affect.

2.1.3 The Non-Affective Aspects of ANS Activity

It is also the case that only a portion of the variance in the ANS activity is driven by affective processes. The ANS is charged with the regulation of some of the most vital of the body's functions and changes in heart-rate, blood pressure, respiration or sweat gland activity reflect a variety of non-affective demands by the system for increased supply of blood, of variations in the need for oxygen and for modulations of body temperature. From the point of view of IP the ANS is quite a noisy system. The "signal," that is, the ANS activity driven by affect, may be swamped or masked by the "noise," the ANS activity that is related to the vegetative and energetic functions of the system.

The factors enumerated above are, in part, responsible for the ability of individuals to produce, or to suppress, ANS activity as their circumstances require. The susceptibility of the ANS for control using biofeedback makes it even more vulnerable to voluntary control by the subject, especially for appropriately trained individuals. Control techniques may range from the voluntary generation of affect by cognitive control to the activation of bodily parts so as to create energy needs that will be reflected in ANS responses at critical points in the interrogatory sequence.

2.1.4 The utility of psychophysiological monitoring

The discussion of the complex of problems that must be solved in order to implement an effective psychophysiological monitoring system is not intended to imply that such monitoring is without value. Quite the contrary is the case. There is a large, and increasing, array of methods that permit effective monitoring in a large number of domains. My intent is to emphasize that the application of psychophysiology to monitoring of humans will require much care.

One of the dangers presented by psychophysiological measures is that they are relatively easy to employ in a shoddy manner. The equipment is generally simple and easy to attach and its output has an air of verisimilitude that can be quite deceptive. The numbers, and the curves, project an authority to which they have a right only if employed by a psychologically sophisticated investigator. Unless the setting is right and the monitoring is conducted within very strict boundaries the output of the measuring instrument may be data, but these data certainly do not provide information. I will return to these remarks when I come to discuss the commercialization of psychophysiological measurements.

With these caveats in mind we can examine some of the monitoring procedures that have emerged over the last several years as powerful psychophysiological tools. I will begin with an enumeration of various techniques spanning the range of available monitoring procedures. I will then focus on the ERP and enumerate the variety of monitoring options provided by this particular class of measures. This will lead to a focus, as an illustration, on one of the components of the ERP, the P300.

2.2 Varieties of Psychophysiological measurements

The repertoire of bodily signals that are available for Psychophysiological measures can be classified according to the nature of the signal being monitored. A classification will be presented in this section.

2.2.1 Motions

In this class belong measures that depend on the recording of muscular movements. We exclude, of course, the general class of muscular responses that are considered overt responses (whether voluntary or involuntary). The functions monitored reflect largely unconscious, involuntary movements, though in most cases people can gain control over the measures. For example, respiration is normally a automatic process. However, people can inflate or deflate their air cavity, within certain limits, if they so wish.

a. Respiration

Measures of the changing volume of the lungs as air is inspired or expired are obtained with relative ease by encircling the chest with a pneumatic tube and monitoring changes in its state as the chest inflates or deflates. Affective reactions often involve changes in the period of the respiratory cycle and in the amplitude of the cycle. These reactions are often among those to which the Interrogative Polygrapher pays much attention. A detailed review is provided by Kaufman and Schneiderman (1986.) Their summarizing conclusion is worth quoting in full as it points to future developments in the use of this index that move it from the category of mechanical indices to that of the chemical indices.

> "Although a knowledge of pulmonary volumes and capacities during behavioral experiments can tell us a lot about relationships between breathing activities and behavior, knowledge about the consumption of O_2 and the excretion of CO_2 provides a more direct picture of the metabolic changes that occur during behavioral situations. Use of an ear oximeter, the Douglas bag, a servo-controlled O_2 monitor or a blood gas analyzer can provide important information about the metabolic changes occurring during psychophysiological experiments. (p 120)"

b. Eye movements

The pattern of eye movements can be readily measured by placing electrodes above and below the eye (i.e. on the forehead and immediately under the lower eyelid). There has been many attempts to use the direction of the gaze as a critical dependent variable in psychological experiments. For example, McConkie and his coworkers have made extensive use of an eye tracker in the study of reading. Stark (1983) has extended his pioneering work on the control of eye movements to the study of psychopathology. Extensive work on eye movements and on blinks as dependent variables was done by John Stern and his colleagues. For a detailed review of this and related approaches to monitoring focusing on the facial musculature see Schwartz (1986).

c. Facial expressions

Paul Ekman has developed a comprehensive method for coding facial expressions in a manner that does not prejudge during the coding process the emotion that underlies the expression. Thus, rather than code expressions as "frowning," "joyous" or "threatening," the Ekman scheme describes the facial expression as a pattern of movement in the facial musculature. With this tool in hand Ekman and his colleagues studied the relation between facial expression and affect and provided a most effective set of tools. Theirs is probably the single most innovative approach to the study of the psychophysiology of affect in the latter half of this century. For a technical treatment of the subject see Ekman and Friesen (1984). For an excellent description of the application of this approach to "Lie Detection" see Ekman (1985).

d. Pupillary dilations

As Beatty (1986) notes in a detailed review of the psychophysiological value of the pupillary system "the primary use of pupillometry in psychophysiology is in the study of brain activation and arousal, (p. 43)". Pupillary diameter can be monitored relatively easily, though the analysis of the data may be rather laborious. Simply stated, mental effort appears to cause the pupil to dilate. The study of the pupil has a long and venerable history (Hess, 1975; Khaneman, 1973) and modern pupillometers allow observation of the pupillary diameter regardless of head motion and direction of gaze. Albeit that such unrestricted monitoring requires at this time fairly expensive equipment (by the standards of psychological research where an instrument costing $10,000.00 is considered pricey).

e. Plethysmography

The plethysmograph measures cardiovascular activity by monitoring the volume of the extremities, usually the finger or the earlobe. It is one of many psychophysiological measures of the heart's activity and does not require a special discussion here except as an example of the variety of mechanical means that can be used for monitoring various functions.

2.2.2 Voltages

In this class we include measures in which the recording instrument is sensitive to voltages generated within the organism as a consequence of the activity of the bodily organ.

a. Electroencephalogram - (EEG)

Voltage differences between two points on the scalp that are due to ionic flows within the brain and the fields generated as a consequence of the summation of large population of individual neurons, (see Allison, Wood and McCarthy, 1986; a very extensive analysis of the physical foundations of EEG analysis can be found in Nunez, 1981).

b. Event Related Brain Potentials - (ERP)

A subset of the EEG. The ERP represent that component of the electroencephalographic activity that is time-locked to external or internal events. It is extracted by computer analysis from conventional EEG. This class of measure is discussed in detail in section 3 of this report.

c. Electrocardiogram - (EKG)

Voltages generated in the course of action of the heart muscles. The signal is recorded by means of the standard cardiographic procedures can be analyzed for a number of parameters ranging from the global analysis of the Heart Rate to the minute examination of the wave shape of the EKG which is widely used in clinical medicine. Even though classical psychophysiology is essentially cardiovascular psychophysiology it will not be discussed in detail in this report as much material is readily available. The chapter by Larsen, Schneiderman and Pasin (1986) provides a detailed review.

d. Galvanic Skin Response - (GSR)

The common measurement associated with the GSR is actually a measure of changes of resistance rather than of voltage. However, these changes of sweat gland activity that have played an important part in the history of Psychophysiology has a voltage counterpart, discovered by Féré. For a review see Fowles (1986).

2.2.3 Other measures

In this section I will enumerate a number of additional measures that cannot be easily categorized.

a. Metabolic changes

This is probably the most exotic, and the most rapidly developing, mode of monitoring. In general the technique labels chemicals that are utilized in a brain process with a radioactive label and a computer aided monitoring system tracks the behavior of the compound over an epoch. It is possible to reconstruct from these data the progress of action in different brain structures. When subjects are engaged in various psychological activities it is possible to determine by these techniques which different brain structures are involved in a specific activity and to what extent.

It is not clear at this time with what resolution would these techniques serve as monitors of human information processing. At this time they all depend for their success on the integration of measurements taken over periods measures by seconds, or by minutes. Thus they seem more suitable for monitoring state variables rather than specific responses. However, the development in these approaches has been, and is, explosive and therefore predictions should be made with great care.

b. Magnetic measurements

The electrical activity of the brain has, of course, a magnetic counterpart. The very small amplitude of the magnetic activity delayed the development of the measure. However, in the last decade a technology based on the use of superconducting probes has developed and it allows the recording of magnetic brain activity both as continual signal analogous to the EEG, and as an evoked responses analogous to the ERP.

At present the magnetic recording requires rather expensive and cumbersome equipment. Large "Squids" must be used and a supply of liquid helium is required. At the most sophisticated it is possible to record from 14 simultaneous probes. However, a system that supports such a recording montage sells, in 1986, for around one million dollars. A number of research programs attempt to develop smaller detectors. Should these become available the obvious advantages of the magnetic recordings will greatly accelerate their use (See Beatty, et. al 1986). The most important aspect of the Magnetic Evoked Field is that it is possible to infer, with some precision, the locus of the intracranial generating source of a magnetic field from the scalp distribution of the field. That is, a map of the distribution of the strength of the magnetic field at different scalp locations provides the data necessary to identify the location of the field within the skull. It is not possible to perform the equivalent analysis using ERPs because the electrical potentials are volume conducted in the skull and the same scalp distribution can be generated by an infinity of sources.

c. Temperature changes

It is possible to sense body temperature externally. Several investigators have proposed that such changes may be useful in

Psychophysiological monitoring. However, these techniques have not been developed to any serious extent (see Schwartz, 1986)

2.3 The Psychophysiological Signal - Criteria for Monitoring

As is true of all technologies, their proper application requires careful attention to details. The purchase of a polygraph and the availability of a subject to whom the polygraph can be attached (or whose brain can be scanned by a CAT scanner) guarantees that the investigator will have curves, or pictures, to show. However, these will be of no value if they were obtained without proper attention to methodological, and logical, aspects of the recording. In evaluating monitoring techniques it is important to assure that the following criteria have been properly considered.

a. Proper methodology

The utility of the measurements depends, almost by definition, on the technical quality of the effort. It is important, however, to realize that "technical" considerations are not exclusively related to the instruments in use. Of course, one must assure that the equipment is properly maintained and adequately calibrated. The bandwidth of the recording must be broad enough to include the signal of interest. To the extent that digital analysis is involved such matters as the digitizing rate and resolution are critical.

However, attention must also be paid to the biological and the psychological adequacy of the effort. By way of example of the biological cautions that must be observed we note that the body is a source of many signals and that some signals may appear to the recording instrument in the shape and form of the signal of interest. In other words, the body itself may be a major source of measurement artifacts. Thus, movements of the eye ball that may in one context be the signal of interest have a time course and a shape that makes if very easy to take oculographic signals as if they are ERPs. It is the investigator's responsibility, whenever ERPs are the target of measurement, to ascertain that the data presented are not confounded by oculographic noise. Several techniques are available (see Gratton, Coles and Donchin, 1983) that serve this purpose and the extent to which these are used determines the value of the ERPs as a monitoring tool.

There are of course innumerable such cautions, many for each of the techniques enumerated. The relevant conclusion for this discussion is that the application of Psychophysiological monitoring is not a matter for amateurs. It is not possible now, and will probably not be possible in the future, for anyone to purchase off the shelf instruments and to use these for accurate and valid monitoring. Extensive training in the finest details of the engineering, biological and psychological aspects of the recordings is a necessary condition for such applications.

b. Construct validity

Attempts to use psychophysiological signals for the monitoring of psychological processes require that the psychological constructs used in the analysis be properly validated. That is, if one proposes that, say, blushing is correlated with "embarrassment," one is relating a physiological response that can be measured, given the precautions mentioned above, to the psychological construct "embarrassment." Evidently such a relationship can be of interest only if it has been made very clear how "embarassement" has been defined and measured and that the psychophysiological assertions undelying the assumption that measure X monitors construct Y are indeed meaningful.

c. Unambiguous psychophysiological relationships

The proper validation of the constructs is a necessary but not a sufficient condition for the success of monitoring. It is usually far from easy to establish the distinctness of such constructs. Is, for example, "embarassement" distinct from "arousal?" How does one tell when subjects are "aroused" without being embarrassed and when they are embarrassed without being "aroused?" These, of course, are very difficult questions that serve as the substance for much of psychological theory. However, they evidently lie at the heart of much of the controversy surrounding psychophysiological applications. The most widely known example being the disputes regarding the use of polygraphy in Lie Detection where the activation of ANS measures may be attributed to the operation of several psychological mechanisms only one of which, presumably, indicating that the subject has been deceptive.

d. Cost of system should not be larger than the benefit of the information

On this point not much need be said. In virtually all cases psychophysiological monitoring is expensive. Equipment is a necessary component. The more elaborate the technique the larger the data base that is generated and all the data need be stored and analyzed. There must be full access to normative data bases. Furthermore, in many of these techniques the subjects must come to a recording site where the equipment resides. Thus, the benefit of the gain in information derived from the use of the equipment must be carefully weighed against the cost of obtaining the information. No general rules can be developed as the issue need be resolved in each setting.

(Of course, as technology develops and as the demand for equipment increases, creating a substantial market, the size and the cost of the equipment may decline. Consider, for example, the wide availability in the mass market of tools for the measurement of blood pressure and heart rate as these have become a matter of personal use in the health monitoring and exercise domain, multiple units whose fields are so aligned that they summate to produce recordable potentials.)

With these criteria in mind we proceed to examine in some detail one psychophysiological index, the Event Related Brain Potential (ERP). We will describe the measure, discuss briefly the recording procedures and list some of its components, each of which can be used in monitoring. For reasons that have largely to do with the personal interests of the author we will examine in much detail one of these components, the P300.

3.0 The Event Related Brain Potential

3.0.1 An overview of the technique

The data we discuss here are obtained by placing electrodes on a person's head and recording electroencephalographic (EEG) activity while the person is engaged in a task. Using the technique of signal averaging, we then extract from the EEG (a voltage x time function) estimates of the portion of the voltage (the ERP) that is time-locked to some event of interest. We assume that these ERPs represent the synchronized activity of ensembles of neurons.

A distinction is usually made between "exogenous" components, which occur early (within the first 100 msec) and "endogenous" components, which occur later (Donchin, Ritter, & McCallum, 1978). Exogenous components reflect early neural processing of the features of the stimuli presented. They are obligatory responses to stimuli whose amplitude and latency are responsive to changes in the physical characteristics of the stimulus, and whose scalp distribution is determined by the sensory system activated. In experiments designed to investigate these early components, subjects typically lie passively while stimuli are presented, often at very high rates (10 times/sec is common in auditory paradigms).

In contrast, cognitive psychophysiological paradigms often challenge the subject with complex tasks, and the subject always has some task to perform. Several attributes of the task are manipulated and serve as the independent variables of the study. Systematic changes in brain activity measured at the scalp are considered representative of the engagement of different neural processes, and serve as the dependent variables. The complex brain response is analyzed for patterns of activity that are characterized by a distinct scalp distribution and by a consistent relation to task variables. These are defined as the endogenous components of the ERP. Such components are distinguished by the fact that they are not obligatory responses to physical stimuli; whether they will or will not be elicited depends on the nature of the information processing required of the subject.

The endogenous components that follow a warning stimulus and precede an imperative stimulus, for example, are believed to be manifestations of intracranial processes that are involved in the subject's processing of the warning stimulus and preparation for a forthcoming stimulus. Endogenous components that follow a task-relevant stimulus depend more on the processing demands imposed by the task than on the physical nature of the eliciting stimulus (Donchin, 1979, 1981). In contrast to the exogenous components, they can also occur long after the stimulus (often between 500 and 1000 msec).

Although the endogenous components of the ERP can be recorded with reliability, the source of these components is not known. Evidence has begun to accumulate that suggests that some of these components may not be generated in the cortex (Halgren, Squires, Wilson, Rohrbaugh, Babb, & Crandall, 1980; Wood, Allison, Goff, Williamson, & Spencer, 1980). There is a hint from this work that we may be observing neural activity generated, in part, from archicortex (the hippocampal formation) and/or the subcortical amygdaloid nuclear complex. Some of the more compelling data, obtained in studies of patients with indwelling electrodes, have led Wood, et. al (1980) to conclude that one endogenous component, the P300, may not reflect the activity of a unitary generator. They suggest that this component represents the summed activity of multiple sources with multiple orientations (see also Okada, Kaufman, & Williamson, 1983).

The ERPs provide a rich class of responses that may, within the appropriate research paradigm, allow the study of processes that are not readily accessible to experimental psychologists by other means. The key assumption of cognitive psychophysiology is that ERP components are manifestations at the scalp of the activity of specific intracranial processors. Our reference is not to specific neuroanatomical entities, but rather to specific functional processors. While networks of nuclei may be involved in a dynamic fashion in the activity represented by each ERP component, our current understanding of the underlying neuroanatomy is insufficient to generate meaningful neuroanatomical hypotheses. Yet, the available data, regarding the consistency with which certain components measured at the scalp behave, permit us to hypothesize that these components do signal the activation of internal "subroutines."

The discussion above should not be construed as implying that the electrical activity recorded at the scalp is itself of functional significance. For our purposes, the ERPs may be due solely to the fortuitous summation of electrical fields that surround active neurons. Although some have argued that EEG fields do have functional significance (especially persuasive is Freeman, 1975), we can remain agnostic on this issue. For our purposes, it is sufficient that we elucidate the functional role, in information-processing terms, of the subroutines manifested by the ERP components. It will, of course, be of considerable interest to obtain a detailed neurophysiological description of the neural implementation of the subroutine. However, a description of the subroutine as a processing entity is of interest independently of the neurophysiological description.

3.0.2 The benefits of ERPs in monitoring

The principal benefit that may accrue to monitoring from the introduction of ERPs into the repertoire of the investigator is the more direct contact they provide with cognitive, rather than with affective, activity. As in ANS-based IP, the investigator's task is the creation of conditions in which knowledge unique to the guilty will reveal itself by triggering a specific, and uniquely interpretable, response. The ERP responses, however, are manifestations of specific information processing activities, not of specific emotional responses to stimuli. As far as we can tell, the activation of the appropriate internal subroutines is always accompanied by the appearance of the appropriate ERP component. To the extent that the subject processes the information in a certain manner and the processing manifests itself in an ERP component, the appearance of the component tends to be obligatory. This is not to say that any ERP component is an automatic candidate to use in monitoring. However, there are some very strong indications that the technique can be of considerable utility.

3.1 The Vocabulary of ERP Components

It is important to emphasize that the P300 is not the only ERP component that can be employed in Monitoring. The ensemble of information processing activities manifested by the ERPs is already quite rich. Additional components are being discovered and deeper understanding is being reached of components which have been known since the mid-60's. In principle, almost all of these components can be utilized in monitoring.

a. N100 - Direction of Attention

Hillyard and his associates (see Hillyard and Hasen, 1986) have shown that the N100 component (recall that components are labeled as <N>egative or <P>ositive, and the number following the character refers to the modal latency of the component) is affected by the directions of the subject's attention. Events in the focus of attention tend to manifest a somewhat larger N100. The effect is reliable. It can be used to monitor changes in the directions of the attention, or changes in the attentional level. Thus, the N100 can play a role either in ascertaining if the subject is actually following instructions with regards to the allocation of attention, or to determine if events in the environment have caused the subject to shift attention. In a way, the N100 is sensitive to "affective" processes as are the ANS responses. Yet, it is likely to be less susceptible to subject-controlled actions.

b. N200 - Detection of Mismatch

Considerable evidence exists that the N200 is elicited by events that violate a subject's expectations, even if they occur entirely outside the focus of attention. Thus, the N200 seems to be a manifestation of the activation of a "mismatch" detector. This component is, it would seem, the least susceptible to control by the subject's voluntary actions. The occurrence of any deviation from regularity, indeed any mismatch between an event and its immediate predecessor, elicits an N200. Thus, with the proper setting and with adequate recording equipment it may serve as an exceptionally effective tool in monitoring (see Naataneen, 1985).

c. P300 - Updating of Working Memory

We have already referred to the P300. It may be useful to note that in addition to its amplitude, that can play a useful role in monitoring, the latency of the P300 has proven an excellent indicator of mental processing time. Since the elicitation of the P300 depends on the categorization of the events in the oddball sequence, then its latency is evidently a function of the duration of the categorization. A variety of scenarios suggest themselves for utilizing the P300 latency in IP.

d. Readiness Potential - Preparation to Respond

The Readiness Potential and the Contingent Negative Variation are among several ERP components that we call Event-Preceding Negativities (see Ritter, Kelso, Kutas, and Shiffrin, 1984). They are quite clearly related to the activation of preparatory, often unconscious, processes by the subject. In recent work we have shown that it is possible to determine, from the extent to which these potentials are larger over one hemisphere rather than the other, which response the subject was contemplating regardless of the response that has actually been made. This feature of these components makes them a very strong candidate for use in IP as they appear to provide a means for assessing conflicts that occur before a response is emitted.

e. N400 - Semantic Mismatch

Kutas, in an extensive series of studies (see Kutas, Lindamood, and Hillyard, 1986), has shown that words that are in some way incongruous, or unexpected, within a discourse elicit an ERP component that is negative and has a latency of about 400 msec. In a way this appears to be a "semantic" component that is elicited by unexpected events. However, it is uniquely associated with linguistic stimuli. Its promise in IP is substantial.

4.0 ILLUSTRATION: THE P300 AND THE ODDBALL PARADIGM

In this section we will discuss the manner in which the P300 component can be used in monitoring. As is true of all other ERP components the P300 is extracted from the ongoing EEG by signal averaging. Its measurable attributes are the amplitude, the latency and the distribution of the potentials across the scalp. These can be used in various combinations in domains as disparate as clinical neurology and human factors. However, much of the use depends on the integration of one basic paradigm, the so called "oddball" paradigm, into the monitoring situation. That paradigm will be discussed in the next section. The manner in which it is employed in a diversity of monitoring situations will then be reviewed.

4.0.1 Description of the Oddball Paradigm

The procedures for using P300 may serve as an illustration of the conceptual issues described thus far. We normally study the P300 in the context of the so-called oddball paradigm. In this procedure the subject is presented with a series of events. The critical attribute that defines a series as an oddball paradigm is that there is a classification rule that categorizes all the events in the series into two categories. The classification rule can range from the concrete to the abstract (i.e., frequency differences of tones, exemplars of two different categories). The events can be quite diverse and the categorization may depend on an ensemble of properties of the events.

Another critical attribute of the paradigm is that the events from each of the two categories are chosen at random and that one of the categories is selected much less frequently than the other. Finally, it is necessary that the subject be assigned some task that requires active processing of the events. When these conditions are satisfied, then events that belong in the rare category elicit a large P300, whose amplitude is inversely proportional to the probability of the eliciting event-category and directly proportional to the relevance of the event to the subject's task. It appears from research that we, and others, have conducted in the last 15 years, that the P300 is a manifestation of the activation of processes that are involved in the maintenance of working memory. The activation of these processes is non-conscious, except in the sense that the subject does consciously monitor the events. Furthermore, as far as we can tell, the P300 is an obligatory response to the event, if the subject is in fact processing it.

The utility of the paradigm in monitoring environments is that it provides a rather standardized measuring tool that can be easily ported from one situation to another. The following attributes of the P300 have been utilized in various models of monitoring:

a. As the P300 is commonly elicited by rare, task relevant, events it can be used to infer which events in a series to which the subject attends were perceived as being rare events. In other words the P300 can be used to determine if an event has surprised the subject.

b. The lower the probability of the event, the larger would be the P300. Thus, all things being equal, the amplitude of the P300 can be used as an estimate of subjective probability assigned by a subject to events.

c. The more attention the subject directs to a task the more likely are stimuli associated with that task to elicit a P300. These task relevant stimuli generally have to be rare to elicit a P300. However, if the subjective probability is held constant and the subject attention drifts away from stimuli the amplitude of the P300 will decline. This characteristic underlies the use of P300 in the monitoring of mental workload.

d. The latency of the P300 is proportional to mental processing time. Therefore it can be used as a means for monitoring mental timing in a manner that is not contaminated by motor activity.

4.0.2 The use of P300 in the assessment of Mental Workload

It is possible to use the P300 as a metric for Mental Workload. The technique is somewhat indirect, but it is in keeping with the general tradition of Workload measurement. We have adopted a technique called the secondary task procedure. An example may help. Suppose one is driving a car on a highway and carrying out a conversation with a companion. Driving the car is the "primary task" and the conversation is a "secondary task." (While it is perfectly possible to think of a situation in which the conversation may be more important than the driving, in our example this is not the case.) Now, as long as the traffic is light and the weather is good and one knows the way, the conversation flows naturally. It is easy to follow a companion's train of thought and one can articulate one's views with great eloquence. Then, the traffic becomes heavy; the driver is in the left lane and must pull to the right to exit on the very next exit. The driving is still smooth. There is no drop in speed. The lane change is executed in a timely and efficient manner. In other words, the performance of the primary task has been protected. But, this is done at the expense of the secondary task as is evident from the fact that the driver stopped attending to the conversation. The answers become laconic and, in the end, irrelevant.

Thus, the pressure experienced in connection with the primary task which did not reflect itself in the driving, did cause a deterioration in the performance of the secondary task. If we had some measure of secondary task performance we could determine the difficulty of the primary task by measuring the deterioration in the performance of the secondary task. The trick is to find secondary tasks that provided a usefully gradable measure of performance and which can be combined with primary tasks without affecting in turn the primary task. Research conducted primarily at the Cognitive Psychophysiological Laboratory at the University of Illinois has shown that the oddball paradigm can serve as such a secondary task and that the amplitude of P300s elicited by stimuli associated with such secondary tasks will vary inversely with the workload associated with the primary task (Donchin, Kramer, & Wickens, 1986).

4.0.3 The use of P300 at a mental prosthesis

A project currently under way at the Cognitive Psychophysiology Lab at the University of Illinois uses the P300 in a tool designed to allow a person who has lost all control of his musculature, and has no speech, to communicate words to a computer. This is achieved by converting a matrix in which 36 different items are turned into an oddball paradigm. The latter the subject is thinking is the mode to elicit a P300. Note this is an example of a technique which appears to be the ultimate in mechanical mind reading but which in effect is no more than a trick which allows the subject to turn a switch with his brain waves rather than with a finger. The key to success, as in all such monitoring, lies in the setting of the situation in which the data are acquired rather than in the data acquisition approches.

5.0 PSYCHOPHYSIOLOGICAL MONITORING AND PRIVACY

If we can indeed make such powerful inferences from the ERP, we do seem to have the capacity to "read the mind." We have on hand a psychophysiological tool that gives its user what may appear to be quite a disturbing power. The worries have indeed surfaced. Take for example a fairly lengthy article carried on June 3, 1984 by the Washington Post. The article was written by correspondent Michael Schrage and was entitled "Technology Could let Bosses Read Minds." The article continued on the following page under the headline "Privacy Veil May Block Brain Watchers View." Schrage reports that "Researchers in both Academia and industry say it is now possible to envision a marketable product that could instantaneously assess whether employees are concentrating on their jobs by analyzing their brain waves as they work..." He tells us that Westinghouse Research and Development Center in Philadelphia is "exploring the use of brain wave analysis - particularly the brain wave known as the P300 - as a means of determining the individual's level of attention and cognitive processing." A Westinghouse man is quoted as predicting that "within the next 10 years Westinghouse could market a complete system capable of monitoring the mental processing effort of employees as they worked..."

This discussion inevitably leads Schrage to discussions with legal scholars and labor leaders regarding the invasion of privacy implied by these developments. While the present report does assert the feasibility of the enterprise described by Westinghouse, I am less inclined to worry about invasion of privacy. The most likely misuse of psychophysiology will be the

Polygraphyzation of the research conducted with the ERP over the past 20 years. By Polygraphyzation I mean the adoption of scientific discoveries for commercial utilization without adequate attention to the effectiveness and utility of the procedure. Polygraphyzation occurs when the commercial development is done without an anchor in the scientific community. Actions are taken to assure the profitability of the product and caution and control become less critical. Training is minimal and tends to be highly professionalized. I emphasize that all this is done well within the law. But, it remains the case that it is quite possible to have what appears to be an impressive instrument that is essentially worthless.

5.0.1 The issues presented by the P300 data

Let us take a few minutes to consider the issues raised by the P300 data. It is clear that in laboratory conditions we can "read the mind." One can think of any number of applications for such a procedure, and few have been described above. However, if one is offered a box in which a pointer is driven to the right or to the left by the magnitude of the P300 as a function of some mental process two classes of questions arise.

There is the question of utility. Does the technique really work? How general is the utility. To date there has not been a test of the P300 based on procedures in valid ecological testing; with the exception of some of the more clinical applications. We know the procedures work well in very complex lab arrangements. Yet there has never been enough support to allow the sort of thorough experimentation in highly normative situations. This issue is, to a large extent, open.

Then there is the issue of Privacy. What is the degree to which monitoring impinges on individual rights? Does it go beyond currently accepted interpretation of the rules? The worry here must be tempered by an understanding of what the machine is actually doing. It is useful to review briefly the constraints on the machine. Also we need to distinguish between two modes of privacy invasion. The popular notion is that it will be possible to achieve the technical feat of making audible by mechanical (or electrical) means those thoughts which constitute our internal speech. Thus, the metaphor driving the worry is that of eavesdropping. But, this has never proven possible.

Eavesdropping on the mind is unlikely. It would only be possible if the signals we can record externally carry within them the richness and the variety available in mental life. One can fantasize, of course, that new technologies will increase the range of the monitoring. Indeed, given the trends in increased computing power and reduced size and cost, some super minicomputer implemented on biological principles might have the power and the savvy to interpret the signals in a depth that matches the profundity of the task. However, it is my belief, that even in that case psychophysiological eavesdropping would not be possible.

To some extent the constraints that could not be eliminated come from the fact that there is too much noise to develop a useful eavesdropping technique. There are too many processes all working in parallel and furiously interacting with each other for there to be a possibility that an external manifestation of any one of these processes will talk to a computer in the same language it talks to its counterparts in the system.

This matter of the "language of the brain" is crucial here. However thought processes are implemented, their implementation is ultimately a matter of neurons talking to neurons. Indeed, it is most likely a matter of millions of neurons talking to millions of other neurons. These neurons converse, of course, with each other by whatever language is used for such communication. There is not yet a full consensus as to the nature of that language. It is clear that in the main neurons affect other neurons by secreting tiny doses of chemicals (the "neurotransmitters"). These secretions are the consequence of the conduction of neuronal impulses across axons and the integrative activities of the dendritic membranes.

We, who study ERPs, benefit from the fact that when occurring in the mass, and in a highly synchronous manner, these inter-neuronal actions manifest themselves on the scalp in the form of large integrated fields of potentials recorded as the EEG. However, this largely epiphenomenal activity while valuable as an index for the time course and level of neuronal action is unlikely to serve as a source of information on the specific nature of the vast exchanges in the neuron's own language that have given rise to these psychophysiological signals.

Thus, it is only the second sense of monitoring that one can assume psychophysiological signals to be of use. We are not, and will not, eavesdrop on the mind. Rather we are observing the consequences of neural action and by judicious construction of the situation we may be able to pose questions to which the psychophysiological signals may give an answer. This metaphor describing psychophysiological monitoring as a process of seeking answers to specific questions is very important because it underlines the principal condition to the success of such monitoring. The value of the answer will depend on the sagacity with which the question has been put. In other words the key to the utility of these approaches is the ability to pose useful questions rather than the procurement of yet another measuring instrument.

Proper application of psychophysiological monitoring requires that one realize that what is being monitored is the activity of bodily systems. These systems are driven for physiological reasons by the demands of the system. These bodily organs serve more than one function and therefore their activity cannot be presumed to be uniquely related to any psychological construct.

The signals we record make sense, therefore, only in terms of situation. There is no "deception" wave - a wave that no matter when and under what circumstances it has been recorded indicates that the person has lied. There is not even a wave that indicates unequivocally that any emotion occurred. Rather, the change in the physical signal indicates the activation of a certain processor, or processors. If, and only if, this is uniquely interpretable within the context of the recording it is possible to make psychological inferences from the data.

Thus the degree to which psychophysiological signals can have psychological meaning depends more on the degree to which the system is set to be driven in a unique fashion by the psychological variables. For example: The workload assessment techniques employing the P300 we described above depend on the establishment of a very sensitive relationship between the conditions of measurement and the subject's ability to perceive the demands.

Unless the subject is performing the two tasks assigned in the dual task setting the measurements of the P300 have no value. Furthermore - intense validation and reliability assessment are still needed.

In other words, active participation of the subject is a condition for the success of psychophysiological monitoring. It is unlikely that it would be possible to apply an unobtrusive probe that will intrude on the subject without at some level the subject accepting the structuring of the situation that constitutes the question addressed to the psychophysiological system.

The above remarks should not be construed as casting doubt on the utility of psychophysiological monitoring. As I indicated above the increasing depth with which these signals are understood and the increasing sophistication of cognitive models when coupled with the spectacular developments in miniaturization, sensor technology and data analysis open a very broad scope for such monitoring. However, this will only be accomplished within the constraints of good methodology. Furthermore, whatever monitoring can be done will be constrained by the nature of the biological and psychological systems involved. One must steer clear of the extravagant claims, and avoid the unnecessary fears that these might invoke.

6.0 THE DANGERS OF COMMERCIALIZATION

It must be emphasized that the remarks made in this report, and in particular in section 6, pertain to the scientifically valid use of the techniques. It is a sad, but obvious, fact that the limits science and nature impose on feasibility do not always serve as constraints on the huckstering of technological pseudo-marvels. That reason, and proper scientific analysis, suggest that eavesdropping on the mind is unlikely does not, unfortunately, imply that the public or elected officials will not be persuaded that a technical miracle has been achieved by someone with a gadget and good marketing technology.

The cases are innumerable in which the gullibility of the market place has served to enrich those who peddle worthless solutions to serious problems. From Snake Oil to Water Divining to, perhaps, Strategic Defense, the public (and its elected and appointed representatives) can be induced to believe in the efficacy of some technique despite the caveats of informed scientists (who, admittedly, can also err).

Thus, this report is addressing solely the issue of the scientific feasibility and the validity of psychophysiological monitoring. Whatever conclusions we draw will not address the degree to which there is a possibility that Industry, or Government, will be induced to believe that a specific technique is indeed valid and that using it is the best one can do in a difficult situation. Under such circumstances vast systems for monitoring individuals may be implemented. That they will be of no scientific value will not reduce their social impact. However, the consideration of public decision making and the sorry interaction between the gullible and the unscrupulous, or the naive, is a matter for Sociologists or Political Scientists not Psychophsyiologists.

7.0 SUMMARY

In this report I surveyed the manner in which psychophysiological approaches may be used, at present and in the near future, to monitor individuals, with particular attention to the monitoring of affective and cognitive responses. A general survey of various indices was followed by a more detailed discussion of the use of Event Related Brain Potentials and in particular the P300 component as a tool in the study of mental functions.

It is concluded from the review that there is indeed a large and increasing potential for the use of psychophysiological techniques. However, we also note that the use of these techniques requires considerable care and that their application requires training and sophistication in the technological, biological and psychological aspects of the work. We emphasize that the monitored data can be interprted only within a detailed understanding of the context of the measurements.

We note that it is unlikely that such monitoring would allow intrusive "reading" of a person's mind. Yet, it is quite possible to arrange recording circumstances that, with the subject's cooperation, could serve to illuminate the content and form of a person's mental activity. Thus, the worries regarding the violation of privacy by such psychophysiological means are exaggerated when couched in alarmist terms, yet these worries are not to be entirely discarded.

A particular worry that rooted in the sociology of technological development rather than in psychophysiology is that a superficial application of psychophysiological findings may lead to widespread employment of devices

purporting to allow monitoring. The fact that these devices are so error prone and ambigous may not affect their widespread use in a manner that would affect decisions regarding individuals' fate. The manner in which the Polygraph is used in personnel screening is a case in point. Thus, even though the real power of the techniques may be constrained and benevolent, the marriage of greed and gullibility that so often determines the action of public bodies does leave room for concern.

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