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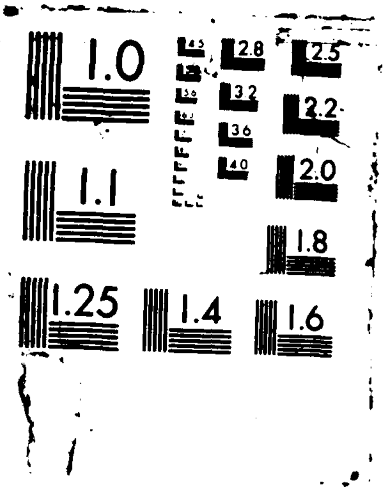
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Endogenous ERP Components Associated with Performance in Sonar Operators:
II. Validation of a Performance Prediction Equation

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Summary

This is the second in a series of reports that constitute the Neurometric Program at the Naval Health Research Center, San Diego, California. The first report established the degree of reliability of the amplitudes of the N150, the P200, and the P400 components and the latency of the P400 components in the event-related brain potential (ERP) (Hord, 1986). Based on the results of the reliability study, a cross-validation procedure using the "half-and-half" idea (Draper and Smith, 1981) was undertaken.

In a cross-validation procedure, first a linear regression or prediction equation was created from ERP data that were obtained through the use of a visual oddball paradigm. Recognition and short term memory were required for the successful completion of the oddball task. Then the prediction equation was used as the basis of the cross-validation procedure.

One hundred and ten subjects were tested and subsequently divided into two samples. The first sample of 56 subjects had a mean age of 22.5 years and a mean experience level of 113 weeks. They were used to develop a prediction equation. The second sample, the validation sample, was composed of 54 subjects with a mean age of 22.6 years and a mean experience level of 74 weeks.

The data for this report were based on the ERPs derived from the C4 lead because the right cerebral hemisphere has consistently been shown to be superior to the left hemisphere for the analysis of visual stimuli that require discrimination (Gazzaniga & LeDoux, 1978). Performance scores derived from the oddball task and an additional sonar-type task were used as the dependent criterion variables in a stepwise linear multiple regression procedure which resulted in the selection of the amplitude and the latency of the P400 component as the best predictors of performance. The amplitudes of the N150 and P200 components were not further evaluated or applied as they did not add to the multiple correlation coefficient, R. The criterion performance scores were shown to correlate positively with sonarman school grades.

The result of the cross-validation procedure showed a significant Pearson correlation of .24 ($p < .04$), validating the regression equation developed previously on a new sample of 54 subjects. The basic conclusion of the present work is that the result of the cross-validation procedure provides sufficient rationale to continue the effort to find a good performance prediction model based on endogenous components of the ERP in sonar operators.

Introduction

Event-related brain potentials (ERPs) are a measure of the electrical activity on the scalp. These measurements are taken by placing electrodes on the scalp at strategic locations, according to an internationally agreed upon schema (Jasper, 1958). After the electrodes are attached, a stimulus is presented to the subject. Then the electrodes conduct the elicited response or electrical voltage from the brain through especially designed equipment to a computer. The electrical response is measured in microvolts and is so small that in order to obtain a higher signal to noise ratio, many trials are averaged together by a computer. This process is called response averaging and yields a usable ERP. Nearly all the sensory systems can be stimulated to evoke ERPs.

Although little is known of the nature of the synaptic events between receptors and the central nervous system, it is known that specific types of stimulation result in a voltage change at the scalp that is unique to the stimulus and to the receptor. An example of this is the brain's response to a flash of light. Such visual stimulation results in the transduction of photons by rods and cones to receptor potentials. Approximately 100 milliseconds (ms) after the visual stimulus is presented to the subject, a change in the brain's electrical activity can be reliably measured. The change is always in the positive direction, relative to a neutral point, and varies in voltage over the scalp. The latency of this voltage change or component is commonly used in the diagnosis of multiple sclerosis (Owen & Davis, 1986).

A similar application of ERP technology has occurred in cases where the integrity of the auditory and vestibular systems is of interest. Here the brain response to very sharp clicks in the ears is evaluated. These auditory stimuli are initially transduced by hair cells on the basilar membrane and ultimately arrive at structures of the brain associated with audition and balance. Such primary auditory ERP components occur in the relatively short time span of ten milliseconds. Within this brief period of time, however, the various positive auditory components of the auditory ERP that define the auditory and vestibular pathways can be recorded and analyzed.

At a very basic level these responses are associated with the synaptic transmission and movement of action potentials at the neuroanatomical structures. It is a common practice to test the integrity of these auditory systems in cases where possible sensory system damage is suspected (Owen & Davis, 1985; Hord, 1981). Similar examples could be given for ERPs that are used to test for anomalous hearing, visual, and somato-sensory states.

Another use of ERP technology that has evolved from the above mentioned clinical applications and is directly relevant to the present study involves a technique of looking at the relationship between environmental stimuli that require a response from a subject and a direct voltage change in the brain. Here, however, the components of interest are the ones that occur from about one hundred ms to about five hundred ms after the presentation of a stimulus (Sutton, Braren, Zubin, & John, 1965). These later occurring components, labeled endogenous, have been associated with a whole new category of stimuli generally referred to as "cognitive" (Donchin, Kubovy, Kutas, Johnson, and Herning, 1973). The premise of this newer use of ERP technology is that the correlates of mental activity or behavior can be objectively measured and analyzed. More and more of these specific correlates of task related cognitive activity are being identified. As this body of knowledge increases, the possibility that mental performance of a precise nature can be measured and monitored becomes more of a reality (Donchin, Wickens, & Coles, 1983; Donchin, Kramer, & Wickens, 1986).

Taken together, the relationships between various kinds of cognitive events and endogenous component measures have led to the hypothesis that the endogenous component measures may be used to improve the selection of certain personnel for special naval jobs. That is, there may be ERP attributes that are unique to individuals who perform well in certain occupations such as sonar operators and air traffic controllers. If those attributes could be identified, it would then be possible to predict the performance of sonar operators and air traffic controllers. Some progress in this direction has been made in the signal detection studies of Parasuraman, Richer & Beatty (1982) and of Kobus, Santoro & Sturr (1987). Although both studies were mainly concerned with differentiating the cognitive processes of detection and recognition they were able to state, to a high degree of accuracy, what the subjects' performance had been on a specified task.

In an attempt to identify the ERP profiles of superior sonarman-type performance, the present study utilized an "oddball" and a dots discrimination task. These tasks required the use of recognition memory, simulated actual field conditions, and were designed in consultation with experienced sonarman. The intent was to use the relationship between observable performance on these tasks and the associated ERPs to develop a sonar performance prediction equation. The ERP components were viewed as predictors, and performance on the cognitive tasks was the criterion variable. The identification of the relevant ERP components associated with these tasks and determination of their reliabilities are documented in Hord, 1986.

Cross-validation is a statistical procedure that is used to evaluate the power of a prediction equation. The question that the cross-validation procedure answers is: how accurately does the prediction equation forecast the performance of a sample of subjects who were not involved in the creation of the equation? In order to accomplish this the most promising predictors of performance are extracted from one sample of subjects, and these same predictors are used to predict the performance of a different sample of subjects. After the predicted performance scores for the second sample of subjects are obtained, they are correlated or matched with their actual performance scores. This correlation procedure yields an index of the strength of the relationship between the predicted scores and the actual scores. Cross-correlation can basically be thought of as the testing of a prediction equation with a different sample than the one used to derive the equation (Yaremko, Harari, Harrison, & Lynn, 1982). In summary, Darlington (1978) has stated that, "...the new techniques *(of cross-validation)* are very useful for pure prediction, as in personnel selection..." (p. 1239).

The primary goal of the present study was to demonstrate the cross-validation (Cohen & Cohen, 1983) of a sonar performance prediction model as it has thus far been developed. The prediction model was based on a stepwise regression analysis derived from the data gathered from a sample of sonar operators. Hord (1986) previously subjected the various ERP component measures to a test-retest reliability procedure and found that four of the measures were significantly reliable from session to session. These reliable measures were used in the multiple (step-wise) regression analysis.

The general hypothesis is that endogenous ERP components can predict performance in sonar operators.

Methods

Subjects. One hundred and sixteen male U.S. Navy sonar instructors and students from the Anti-Submarine School, San Diego, California, volunteered as subjects. In order to provide for a cross-validation of the prediction model, subjects were arbitrarily assigned to one of two sample groups (see Draper & Smith, pp 419-421, 1981). The first sample of 56 subjects was used to generate the prediction model, and the second sample of 54 subjects was used to validate the prediction model. The first sample of subjects contained two subjects with missing ERP data, and the second sample contained four subjects with missing ERP data; therefore, these six subjects were dropped from further analysis. The first group of subjects had a mean age of 22.5 years (S.D. = 4.9 years) and the average length of experience was 113 weeks (S.D. = 187 weeks). The second group of subjects had a mean age of 22.6 years (S.D. = 4.5 years) and the average length of experience was 74 weeks (S.D. = 95 weeks).

Procedures:

Performance Tasks. Each subject completed two visual information processing tasks. For both tasks the subject sat approximately 36 inches from a 12 inch video screen. The first task consisted of a version of the "oddball" paradigm. A checkerboard pattern, composed of approximately 7/16 inch squares, was flashed on the screen 150 times. Each pattern was displayed for 500 ms and the interstimulus interval was randomly variable averaging 500 ms. On 80% of the pattern presentations, the subject had been instructed to only attend to the screen. The remaining 20% or oddball presentations were randomly distributed among the background stimuli. The oddball pattern was a checkerboard reversal of the background stimulus, and for these stimuli the subject had been instructed to remember the number of presentations and to report the total at the end of the session. The ERPs reported here were time locked to the Pattern Reversal trials.

The second visual task consisted of 100 trials on a simulated sonar task. On each trial, a 48 by 76 dot pattern was presented. The background dot density was 50%, with one quadrant set to 60% density and identified as the target. The pattern was displayed for one second without an interstimulus interval. For each trial the subject was instructed to press one of four keys on a key pad that was matched with the quadrant in which the greater dot density was perceived. A central key was also available on which the subject could indicate that he did not perceive a change of target. The measure of performance on the task was the number of correct choices.

For each subject a performance score was obtained by combining their scores on the first (oddball) task and the second (simulated sonar) task. These performance scores were combined by first normalizing the distributions of each task and then obtaining the mean Z scores for the two tasks. This final score was labeled the performance Z score (PZS) and is the criterion variable.

EEG Recording. A Grass silver cup electrode was attached to the scalp at C4 with collodian and referenced to linked mastoids. The use of the C4 site was chosen as the right hemisphere has consistently proven to be superior in the processing of visual stimuli, especially as regards tasks which require discrimination (Gazzaniga & LeDoux, 1978). Impedances were 5K ohms or less. The EEG was amplified X 20,000 by a Grass Model 12A5 amplifier. Movement artifact rejection was accomplished through software. A DEC MINC 11/23 computer digitized the 500 ms sweeps time locked to the Pattern Reversal trials. The signal-averaged ERPs for each subject were then obtained and were the sources of the ERP components.

Data Reduction. A grand mean, across subjects, of the individual ERPs was used to define the ERP components associated with the Pattern Reversal task (see Figure 1) in a previous reliability study (Hord, 1986). This

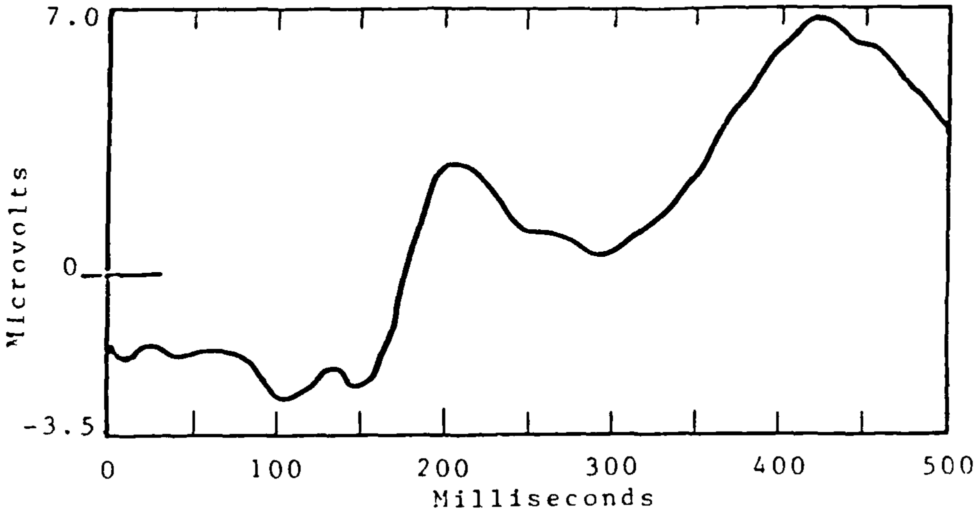

Figure 1. Grand Mean for the Pattern Reversal Task.

grand mean was obtained by signal averaging across the subject sample for the pattern reversal task. In the reliability study the component measures at 150, 200, and 400 ms were analyzed. Amplitude and latency measurements for each component were obtained for each individual by defining windows within which they could be read. The parameters for these windows are given in Table 1.

Table 1. Latency parameters for the N150, P200, and P400 components[a]

Window N150:	150 ms ± 50 ms
Window P200:	200 ms ± 50 ms
Window P400:	400 ms ± 100 ms

[a] N150 is a negative component, and P200 and P400 are positive components.

Cross-Validation: Cohen & Cohen (1983) was used as a basic reference for the cross-validation procedure that was employed in this study. As an initial step in a validity study, the prediction equation derived from one sample of a population is applied to a different sample of the same population; therefore, two samples of subjects were tested. Using the first sample, a prediction equation was generated based on the performance Z score (PZS) and the four reliable predictor ERP variable component measures.

The prediction equation was created by applying a multiple (stepwise) regression procedure (Tatsuoka, 1971), using the reliable components as the independent variables and the PZS as the criterion. A stepwise regression procedure was used in order to reduce the number of predictor variables to those that made a significant contribution to R squared. The result of that analysis indicated that the amplitudes of the components at 150 ms and 200 ms did not add to the value of the multiple R, and, therefore, they were deleted. At this point, a prediction equation existed that consisted of the latency and amplitude of the positive component at 400 ms as predictor variables and the performance measure (PZS) as the criterion variable.

To accomplish the cross-validation procedure the prediction equation was used to predict the performance scores of the second sample. After the predicted scores were assembled there were two distributions of performance scores for the second sample of subjects. One distribution consisted of the predicted performance scores, and a second distribution consisted of the actual performance scores for the second sample. As a final step these two distributions were subjected to a linear (Pearson) correlation procedure.

Results

As the amplitude and the latency of the P400 component and the amplitudes of the N150 and P200 components have been previously shown to be reliable across sessions (Hord, 1986), they were initially considered as the predictor variables in a prediction equation. The performance Z score was the criterion variable.

The means and standard deviations of these reliable evoked potential components (independent variables) and the performance Z score (dependent variable) are presented in Table 2. A summary of the intercorrelations among the reliable evoked potential components and the performance Z score is shown in Table 3.

Table 2. Means and Standard Deviations of the Reliable ERP Components and the Performance Z Score (PZS). Amplitudes are in microvolts (N150, P200, P400), latency is in milliseconds (L400). (N=56).

Variable:	PZS	N150	P200	P400	L400
Mean:	-.017	-4.97	4.61	8.81	398.93
S. D.:	.788	2.12	3.24	4.46	64.21

The stepwise linear multiple regression analysis revealed that the two measures of the P400 component (amplitude and latency) were the best predictors of performance. As can be seen, their correlations with the performance Z score were .28 and -.11 respectively, and their intercorrelation was .35. From these data it appears that the late positive component (P400) is a fair predictor of this type of performance. Furthermore, the components at 150 and 200 ms do not appear to add to the efficacy of a prediction equation. The final prediction equation is:

$$PZS = 1.649 + .066\,(P400) - .005\,(L400)$$

(P400 = the amplitude of the component at 400 ms, in microvolts; L400 = the latency of the P400 component, post-stimulus, in milliseconds)

Table 3 shows that for the first sample the dependent variable (PZS) is significantly, but weakly, correlated with the amplitude of the P400 component. There is no correlation between the criterion variable and the latency of the P400 for the first sample. There was no relationship between the PZS and the P400 amplitude for the second sample.

Final Sonarman "A" school grades, for a subsample of 51 subjects, were correlated with the Mean Performance Score (PZS), the oddball task Z scores, and the dots discrimination task Z scores. A positive correlation r = .29

Table 3. Intercorrelations Among the Reliable ERP Components and the Performance Z Score (PZS).

	N150		P200		P400		L400	
	r	sig[a]	r	sig	r	sig	r	sig
Sample 1 (n = 56)								
PZS	.01	n.s.	.08	n.s.	.28	.02	-.11	n.s.
N150	---------		.06	n.s.	-.31	.01	-.25	.03
P200	---------		---------		.17	n.s.	.04	n.s.
P400	---------		---------		---------		.35	.004
Sample 2 (N = 54)								
PZS	---------		---------		.00	n.s.	-.19	n.s.
P400							.31	.01

[a] sig = significance level.

(p <.02) was found between PZS and the final "A" school grades. Furthermore, performance on the oddball task positively correlated with the final "A" school grades, r = .43 (p <.001). The dots discrimination task did not correlate with the final "A" school grades. Thus, the performance task defined for this study shows good face validity.

The cross-validation correlation was .24 (p<.04). The small, but significant, cross-validation r accounts for approximately six percent of the variance.

Discussion

The results of this study demonstrate that some degree of cross-validation of a prediction model can be achieved with ERP component measures as predictor variables and task performance as the criterion variable. The linear equation was developed from the reliable amplitude and latency component measures at 150, 200, and 400 ms. The amplitude of the 150 and

200 ms components were removed by the final regression analysis because they did not add to the power of the prediction equation.

It was found that the amplitude of the 150 and 200 ms components did not add significantly to R squared. This can perhaps be attributed to the relationship between the component measures as reported in Table 3. Here it can be seen that N150 amplitude was significantly correlated with both the latency and amplitude of the P400 component. These negative correlations mean that as the early negative 150 ms component measures increase, the late positive wave decreases in both latency and amplitude. Since these are correlations between subjects, it means that individuals with relatively large, early negative components will tend to have small, late component measures and, of course, the obverse is also true. This may mean that the variances of these variables are so great between subjects that no additional predictive value could operate in the regression equation.

The amplitude measure at 200 ms did not correlate with the N150 or the P400 amplitude measures. This could be due to the effect of the constant 500 ms interstimulus interval. Such an unvarying interval could have been acting as an anticipatory stimulus, and, therefore, the components may have been influenced by a possible contingent negative variation effect (Ritter, Kelso, Kutas, & Shriffrin, 1984).

The component at 400 ms showed a positive relationship between its amplitude and latency. As the latency increased, the amplitude increased. Again, because these are correlations between subjects, it means that individuals having relatively long latencies will tend to have large amplitudes, and subjects with comparatively short latencies will tend to have smaller amplitude measures.

Although the present study refers to a P400 component, the attributes of the classical P300 component are thought to be almost identical. As Kutas and Hillyard (1984) have stated, "The label P3 or P300 has been used to refer to a positive component of the ERP that has a latency anywhere from 300 to 900 milliseconds" (p. 390).

In the present analysis, the P400 amplitude was shown to be one of two optimum predictors of performance. The cognitive correlates of this component have been extensively investigated and have revealed that the amplitude of the P300 component increases as the probability of a stimulus decreases without regard to the type of task or stimulus (Duncan-Johnson & Donchin, 1977; Friedman, Simson, Ritter, & Rapin, 1975; Johnson & Donchin, 1980, 1982; Kutas, McCarthy, & Donchin, 1977; Picton & Hillyard, 1974); more precisely, the amplitude of the P300 component has been related to the complexity of the stimulus and the task (Chesney & Donchin, 1979; Johnson & Donchin, 1978; Horst, Johnson, & Donchin, 1980; Donchin, Kubovy, Kutas, Johnson, & Herning, 1973; Eason, Harter, & White, 1969); and the stimulus value or significance of the stimulus (Begleiter, Porjesz, Chou, & Aunon, 1983; Johnson, 1979; Steinhauer, 1981; Tueting & Sutton, 1976; Wilkinson & Morlock, 1967). In addition, the latency of the P400 component was shown to be the other best predictor of performance, and this would seem to be logical as the latency of the P300 component has been shown to index the time needed to categorize and evaluate a stimulus (Donchin, 1979; Duncan-Johnson, 1981; Ford, Mohs, Hopkins, & Kopell, 1979; Johnson, Pfefferbaum, & Kopell, 1985; Kutas et al., 1977). Overall, the P300 component measures would appear to be potent measures of performance as Donchin et al., (1986) have demonstrated that the P300 component is an indicator of cognitive workload.

In terms of general personnel selection goals, the results of this study can be viewed as offering a very conservative addition to the selection criteria for certain types of U. S. Navy occupations. However, it remains to be seen if these measures of central nervous system function can be used to facilitate the selection of personnel for the more arduous performance requirements of sustained operations or for the stressful demands of military operations in general.

With respect to the present work, a point that should be considered is that only a few of the possible tasks and measurement methods have been examined. Perhaps new methods of data reduction and more sophisticated displays and more complex tasks would yield better prediction equations. Additionally, it should be emphasized that the present equation was used to predict performance on a simulated sonar task and that it did not attempt the prediction of on-the-job performance or supervisor ratings of performance.

An alternate method of data reduction is currently being evaluated at the Naval Health Research Laboratory, San Diego, California. The goal of this new approach is to attempt to reduce the high variability of the commonly used latency and amplitude measurements by combining the two into a single measurement. This is being done by integrating the area under the ERP wave and then using that measure in place of the individual latency and amplitude measures associated with the various components. The hypothesis implicit in this method is that the area under the ERP wave is associated with performance on sonar simulator-type tasks. If supported, this new measure would provide a better predictor variable for the selection of high level sonar operators, or its antithesis, the rejection of individuals showing central nervous system attributes that are not consistent with high level cognitive functioning.

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(U) ENDOGENOUS ERP COMPONENTS ASSOCIATED WITH PERFORMANCE IN SONAR OPERATORS:
II. VALIDATION OF A PERFORMANCE PREDICTION EQUATION

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A cross-validation procedure was applied to a prediction equation. The equation was developed in order to aid in the identification of high level sonar operators. Endogenous event-related potentials (ERPs) were used as predictors and a performance score on sonar simulator tasks was the criterion variable in the equation. A sample ($n = 56$) of sonar operators was used to create the prediction equation which was then used to predict the performance of a second sample ($n = 54$). The correlation between the predicted and the actual performance scores for the second (validation) sample was .24 ($p < .04$).

It was concluded that using endogenous ERP components, as predictors of performance, may enhance the process of identifying potentially high level sonarmen. The application of the prediction equation to the selection of aspiring sonarmen could be expected to account for approximately six percent of the variance in performance. Therefore, the use of the prediction equation, in conjunction with the other selection criteria, may aid in the reduction of attrition rates.

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