DOCUMENT RESUME

ED 229 623 CE 035 984

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TITLE Brain Event-Related Potential Correlates of Concept Learning.
INSTITUTION Navy Personnel Research and Development Center, San Diego, Calif.
REPORT NO NPRDC-TR-83-16
PUB DATE May 83
NOTE 24p.
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Academic Achievement; Adult Education; Cerebral Dominance; *Cognitive Processes; Educational Research; Electroencephalography; Electronics; Enlisted Personnel; *Fundamental Concepts; Learning Processes; *Metacognition; Military Service; *Neurological Organization; Trade and Industrial Education
IDENTIFIERS Brain Activity; *Brain Research; *Event Related Potentials; Navy

ABSTRACT

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NPRDC TR 83-16

May 1983

ED229623

BRAIN EVENT-RELATED POTENTIAL CORRELATES OF CONCEPT LEARNING

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SE035 984

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER NPRDC TR 83-16	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) BRAIN EVENT-RELATED POTENTIAL CORRELATES OF CONCEPT LEARNING		5. TYPE OF REPORT & PERIOD COVERED Final Report Oct 1981-Sep 1982
		6. PERFORMING ORG. REPORT NUMBER 13-82-11
7. AUTHOR(s) Pat-Anthony Federico		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Navy Personnel Research and Development Center San Diego, California 92152		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62763N ZF63-522-010-03.06
11. CONTROLLING OFFICE NAME AND ADDRESS Navy Personnel Research and Development Center San Diego, California 92152		12. REPORT DATE May 1983
		13. NUMBER OF PAGES 23
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Event-related potentials
Evoked cortical potentials
Hemispheric function
Brain activity
Concept learning
Cognitive process
Human information processing
Electrophysiologial correlates

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An irrelevant auditory probe procedure was employed to evoke brain event-related potentials (ERPs) in 56 Navy recruits while they learned pulsed radar concepts presented to them in study booklets. A mastery test was administered to assess concept acquisition. Test items became criteria for multiple regression and discriminant analyses using as predictors ERP amplitudes that corresponded to specific concepts. One regression analysis and its associated statistics indicated that ERPs recorded at the right temporal and parietal areas are significantly related to concept acquisition. Three discriminant

analyses and their subsequent statistics revealed that ERPs evoked at the right frontal, temporal, parietal, and occipital and the left parietal regions significantly distinguished below- from above-average concept learners. Poorer learners engaged the right frontal and temporal regions less and with greater variability than did better learners, possibly because they processed less concept-related information at these brain locations. This study established that the right frontal, temporal, and parietal areas are significantly associated with concept learning--not only left hemisphere regions as proposed in the popular asymmetric model of the brain.

FOREWORD

This research was performed incident to exploratory development work unit ZF63-522-010-03.06 (Evaluating Evoked Potentials for Navy Training and Testing) under the sponsorship of the Chief of Naval Material (Office of Naval Technology). The goal of this work unit is to evaluate the feasibility of using brain event-related potentials (ERPs) in Navy training and testing.

This is the third in a series of reports prepared under this work unit. The first (NPRDC TR 82-8) discussed the use of ERP analysis to aid in the design of instructional procedures adapted to the information-processing strategies of individual students. It suggested the possibility of increasing Navy training efficiency by taking better advantage of the variabilities that exist among students in their sensory modalities. The second (NPRDC TR 83-11) demonstrated the construct validity of ERPs as indicators of individual differences in student cognitive characteristics, especially crystallized and fluid intelligence. The purpose of this study was to ascertain ERP correlates of concept learning.

The results of this study are primarily intended for the Department of Defense training and testing research and development community.

Appreciation is expressed to Gregory W. Lewis and Jeffrey N. Froning for their cooperation and assistance in the data collection phase of this research.

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SUMMARY

Problem

The research issue was whether brain event-related potentials (ERPs) recorded while students are in the process of learning are correlated with their subsequent achievement and performance. If it was found that brain-wave measures are associated with concept acquisition, then what are their implications for Navy testing and training?

Objectives

The objectives of this effort were to (1) record ERPs as students learned a representative Navy subject matter, (2) determine if these ERPs were correlated with their achievement, and (3) derive implications for Navy testing and training.

Approach

Fifty-six, right-handed, male, Caucasian, Navy recruits had their ERPs recorded while they learned concepts. Irrevelant, auditory clicks presented to each subject over headphones elicited ERP amplitudes at eight recording sites of the brain: left and right frontal, temporal, parietal, and occipital regions. Study materials explaining pulsed radar were administered to subjects in booklets. A criterion test was given to assess achievement. Test items became criteria for 16 multiple regression and 13 discriminant analyses that employed, as predictors, ERP amplitudes corresponding to specific radar concepts.

Results

One regression analysis and its associated statistics indicated that ERPs recorded at the right temporal and parietal areas are significantly related to concept acquisition. Three discriminant analyses and subsequent statistics revealed that ERPs evoked at the right frontal, temporal, parietal, and occipital and the left parietal regions significantly distinguished below- from above-average concept learners. Also, poorer concept learners had higher mean ERP amplitudes and larger standard deviations than did better learners.

Conclusions

Some ERPs recorded as students were in the process of learning concepts seemed to be related to subsequent achievement. The poorer concept learners appeared to engage the right frontal and temporal regions less and with greater variability than did better learners, possibly because they processed less concept-related information at these brain locations. Theoretically, this established that the right frontal, temporal, and parietal areas are significantly associated with concept learning--not only left hemisphere regions as proposed in the popular asymmetric model of the brain.

Recommendation

Even though this study established that some ERPs are significantly correlated with concept learning, the number and strength of the relationships were not of sufficient magnitude to warrant the practical application of ERPs as a basis for the development of adaptive instructional strategies for Navy training.

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INTRODUCTION

Problem

The average ability level of Navy recruits has noticeably decreased and then increased since the all volunteer force was implemented. Consequently, the Navy is seeking innovative training strategies that can be used to adapt instruction to a wider range of student abilities and cognitive styles. In an effort to accommodate training tactics to individual differences among students, the Navy has implemented computer-managed instruction (CMI). CMI is only partially adaptive since students use self-study materials and learn at their own pace. A second strategy, the aptitude-treatment-interaction (ATI) approach, assumes that aptitudes, as measured by customary psychometric tests, interact with instructional strategies or treatments. Research has only partially supported the ATI notion (Cronbach & Snow, 1977; Federico, 1978, 1981). Improved procedures for accommodating instructional techniques to the cognitive attributes of individual students are still needed (Federico & Landis, 1979a, 1979b, 1980).

Another possible approach would be to assess individual differences in cognitive processing first and then develop training strategies that exploit these differences. Recent advances in the computerized assessment of brain activity, especially in the measurement of event-related potentials (ERPs), suggest that this technology may be useful for estimating the cognitive processing of Navy trainees. If so, then it may be possible to design instructional procedures that accommodate the differences among individual students to maximize their learning and subsequent performance. However, before brain-wave measures are employed in this manner, it should be established whether ERPs are correlated with actual concept learning.

Background

Computer technology and measures of brain electrical activity have been applied to the study of cognitive processes. Electroencephalographic (EEG) and ERP records depict brain activity as minute signals obtained from the scalp. The EEG shows on-going activity, while the ERP portrays activity after stimulus events (e.g., light flashes or audible clicks). Typically, for people performing verbal tasks such as reading prose passages, there is decreased activity over the left hemisphere. For spatial tasks such as recognizing random shapes, there is generally a decrease in activity over the right hemisphere. Such decreases may be considered indices of increased information processing within the affected hemisphere.

At least two distinct modes of cognitive processing have been shown to be related to the brain's two hemispheres. A verbal, analytic, sequential, logical mode of cognitive processing has been associated with left-hemisphere activity in most right-handed individuals. Conversely, a spatial, integrative, simultaneous, intuitive mode has been attributed to right-hemisphere activity. These two modes of processing were initially discovered by anatomical studies using subjects with war wounds, lesions, and "split-brains." Some individuals employ a predominantly verbal-analytic cognitive style for learning, problem solving, and decision making, whereas others employ a predominantly spatial-integrative cognitive style (Bogen, 1969; Callaway, 1975; Dimond & Beaumont, 1974; Galin & Ellis, 1975; Galin & Ornstein, 1972; Kinsbourne, 1978; Knights & Bakker, 1976; Lewis, 1979, 1980; Lewis & Rimland, 1979, 1980; Ornstein, 1977).

Many studies have investigated relationships between brain ERPs and indices of intelligence. ERP latencies seem to vary inversely with measures of ability or intelligence (Bigum, Dustman, & Beck, 1970; Callaway, 1973, 1975; Chalke & Ertl, 1965;

Ertl, 1969; Ertl & Schafer, 1969; Galbraith, Gliddon, & Busk, 1970; Gucker, 1973; Marcus, 1970; Shucard & Callaway, 1974; Shucard & Horn, 1972). Yet, some investigations failed to establish such a relationship (Barnet & Lodge, 1967; Engel & Fay, 1972; Henderson & Engel, 1974; Osborne, 1970; Rhodes, Dustman, & Beck, 1969).

Right hemisphere ERP amplitudes and asymmetry measures appear to be directly related to intelligence--although not always (Bigum, Dustman, & Beck, 1970; Galbraith, Gliddon, & Busk, 1970; Perry, McCoy, Cunningham, Falgout, & Street, 1976; Rhodes, Dustman, & Beck, 1969; Richlin, Weisinger, Weinstein, Giannini, & Morganstern, 1971; Shucard & Horn, 1973). Other ERP properties that have been explored with respect to intelligence have been habituation (Barnet, 1971), variability (Bigum, Dustman, & Beck, 1970; Callaway & Stone, 1969; Rhodes, Dustman, & Beck, 1969), and harmonic components (Bennet, 1968; Ertl, 1971, 1973; Shucard & Callaway, 1974; Weinberg, 1969).

A number of experiments have been conducted to explore associations between different aspects of human information processing and brain electrical activity (e.g., Buchsbaum & Silverman, 1970; Donchin, 1975; Donchin & Cohen, 1967; Donchin, Kubovy, Kutas, Johnson, & Hering, 1973; Federico, Froning, & Calder, 1983; Friedman, Guyer-Christie, & Tymchuk, 1976; Horst, Johnson, & Donchin, 1980; Israel, Wickens, Chesney, & Donchin, 1980; Lewis, Federico, Froning, & Calder, 1982; Pizzamiglio, 1976; Ray, Morell, Frediani, & Tucker, 1976; Shearer & Tucker, 1981; Shucard, Shucard, & Thomas, 1977; Squires, Petuchowski, Wickens, & Donchin, 1977; Tucker, 1981; Tucker, Shearer, & Murray, 1977; Wickens, Mountford, & Schreiner, 1981). Hardly any of these investigations reported relationships between ERPs recorded while students are in the process of learning and their subsequent achievement and performance. Are brain-wave measures associated with concept acquisition? If so, what are their implications for Navy testing and training?

Objectives

The objectives of this effort were to (1) record ERPs as students learned a representative Navy subject matter, (2) determine if these ERPs were correlated to their achievement, and (3) derive implications for Navy testing and training.

APPROACH

Subjects

The subjects were 56, right-handed, male, Caucasian recruits from the Naval Training Center, San Diego who were undergoing basic enlisted military instruction. Audition of these subjects tested normal.

Instrumentation

Data were acquired on a field-portable computer system[1] that included a Data General NOVA 2/10 central processing unit (CPU, 32K memory); a dual-drive floppy disk unit (Advanced Electronics Design, Inc., Model 2500); an optically isolated and multiplexing EEG unit, with band pass set for 0.2-30 Hz; and a videographic display unit,

[1]Identification of the equipment is for documentation only and does not imply any endorsement.

integrated into the CPU, that displayed the analyzed ERP data. Permanent storage of all video information was obtained from a video hard copy unit (Tektronix Model 4632) (Lewis, 1979, 1980; Lewis & Rimland, 1979, 1980; Lewis, Rimland, & Callaway, 1977).

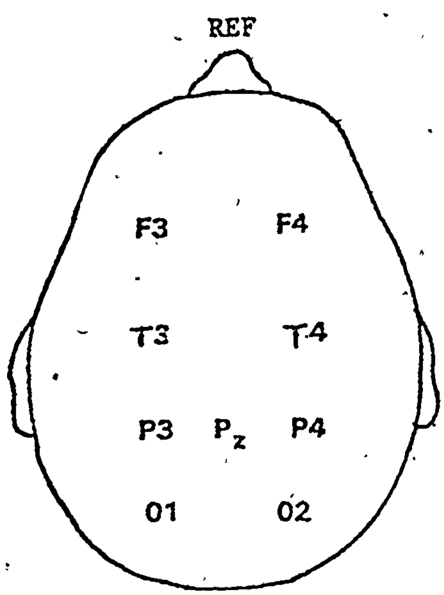
Stimuli

Auditory clicks were presented binaurally over headphones (Sennheiser Model 424X) periodically every 2 seconds. Click intensity was about 65 dB (A) (Bruel and Kjaer Impulse Sound Level Meter, Model 2209, One-third Octave Filter Set, Model 1616). Headphone leads were shielded to minimize click artifacts.

During all recording periods, white noise was used for masking. It was presented to the subjects through the headphones and via a speaker in the sound chamber at a level of approximately 50 dB (A).

Recording Sites

Eight channels of auditory ERP were acquired from four pairs of homologous sites, as shown in Figure 1. Sites F3 and F4 are over the frontal brain region, an association area; sites T3 and T4 are over the temporal region, a primary auditory reception area where many visual and auditory nerves interconnect; sites P3 and P4 are over the parietal region, a primary association area; and sites O1 and O2 are over the occipital region, a primary visual reception area (Jasper, 1958). Ground was at Pz in the mid-parietal area. Sites designated by odd numbers denote left hemisphere locations; those designated by even numbers denote right hemisphere locations.



Legend.

F3 = Left frontal
T3 = Left temporal
P3 = Left parietal
O1 = Left occipital
P_z = Mid-parietal (ground)

F4 = Right frontal
T4 = Right temporal
P4 = Right parietal
O2 = Right occipital
REF = Nose (reference)

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Figure 1. Electrode sites.

Electrodes

The subjects were prepared for recording after they had received brief instruction. They completed a short background questionnaire and signed a privacy act and volunteer consent form. An elastic helmet (Lycra) fitted with plastic holders for the electrodes was placed on the subject's head. Each subject's hair was parted and scalp cleaned with an alcohol-impregnated swab that was placed through the holders. Electrode cream was placed down the holders and rubbed into the scalp. The electrodes were Beckman miniatures (11 mm) with a clear plastic extention tube (38 mm long) attached and filled with electrolytic solution. A small sponge (microcell foam) soaked with electrolyte held the solution in the tube and made contact with the electrode paste on the scalp. The extension tube not only held the electrode in place but also minimized the slow potential drift due to scalp temperature change that would have otherwise been picked up by the recording site. A Beckman mini-electrode fitted with a standard two-sided adhesive wafer served as a reference electrode on the nose.

The helmet and all three electrodes could be attached in 6-8 minutes with impedance readings of 2-3K ohms. After all electrodes were in place, the subjects were instructed to observe their real-time EEG activity on the oscilloscope display. They were then instructed to move their jaws, eyebrows, etc. so that they could observe how muscle artifacts could contaminate the ERP data. The subject was then seated in a sound chamber in alignment with the video monitor. A hand-held switch allowed the subject to suspend all stimulus presentation and analysis operations to eliminate artifact. Additional artifact rejection was available by the console operator prior to storing the data.

ERP Data

The auditory ERP data were retrieved from a floppy diskette and the required computations were performed. The data were then displayed on the video monitor and hard copies were obtained.

Eight channels of auditory ERP data are overlaid in Figure 2. Standard deviation (SD) amplitude values are presented along with the waveform mean values for half-second post-stimulus epoch (512 msec). SD amplitude values (in μV) are normalized (waveform mean set to zero) RMS values (in μV). For all analyses, only SD amplitude values (in μV) were used. Calibration, polarity, DC offset, time base, and other descriptive information were also displayed. The waveforms from top to bottom were from the front to the back of the head at frontal, temporal, parietal, and occipital sites (F3, T3, P3, O1). Right hemisphere (RH) ERP data from sites F4, T4, P4, and O2 were presented in the right column.

Concept Learning Materials

Concept learning materials consisted of elementary electronics support measures (ESM) ideas dealing with pulsed radar (e.g., radar components, pulse duration, pulse repetition frequency and interval, nautical mile, and distance a pulse travels in a microsecond). Figure 3 presents a sample of this concept learning subject matter.

Procedure

The concept learning materials were administered to each subject in a study booklet. An "irrelevant auditory probe" technique was used to elicit ERPs while the subjects actually studied the concept materials. As each subject learned each new page of concepts, ten 65 dB (A) clicks were presented randomly with an averaged interstimulus

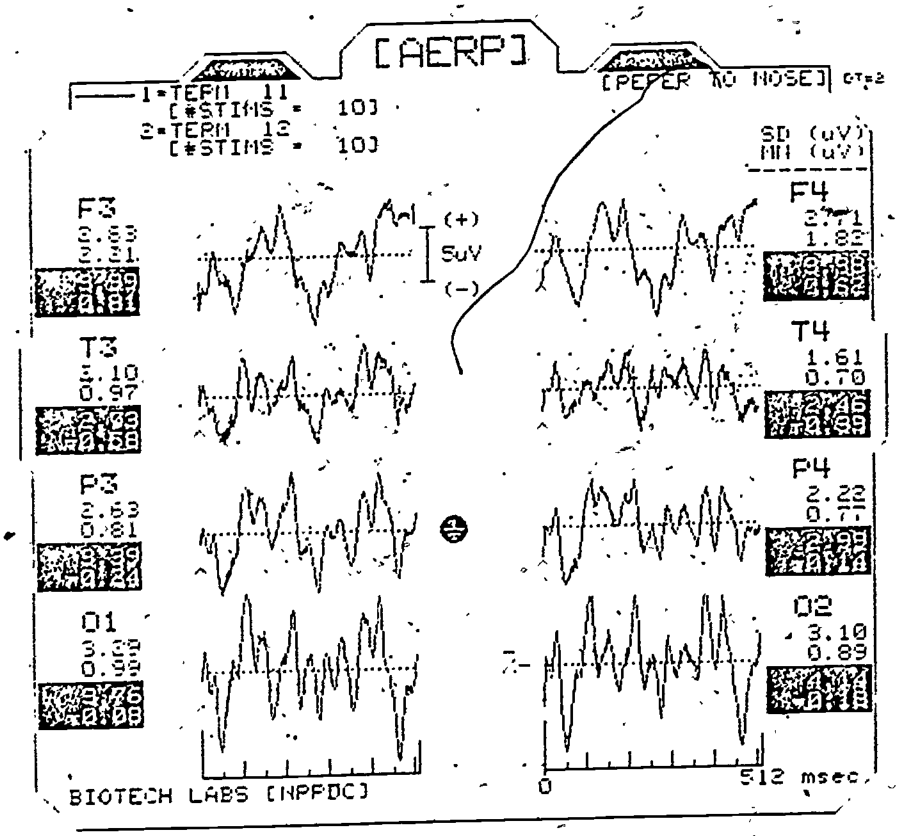

Figure 2. Example ERP overlay for eight channels.

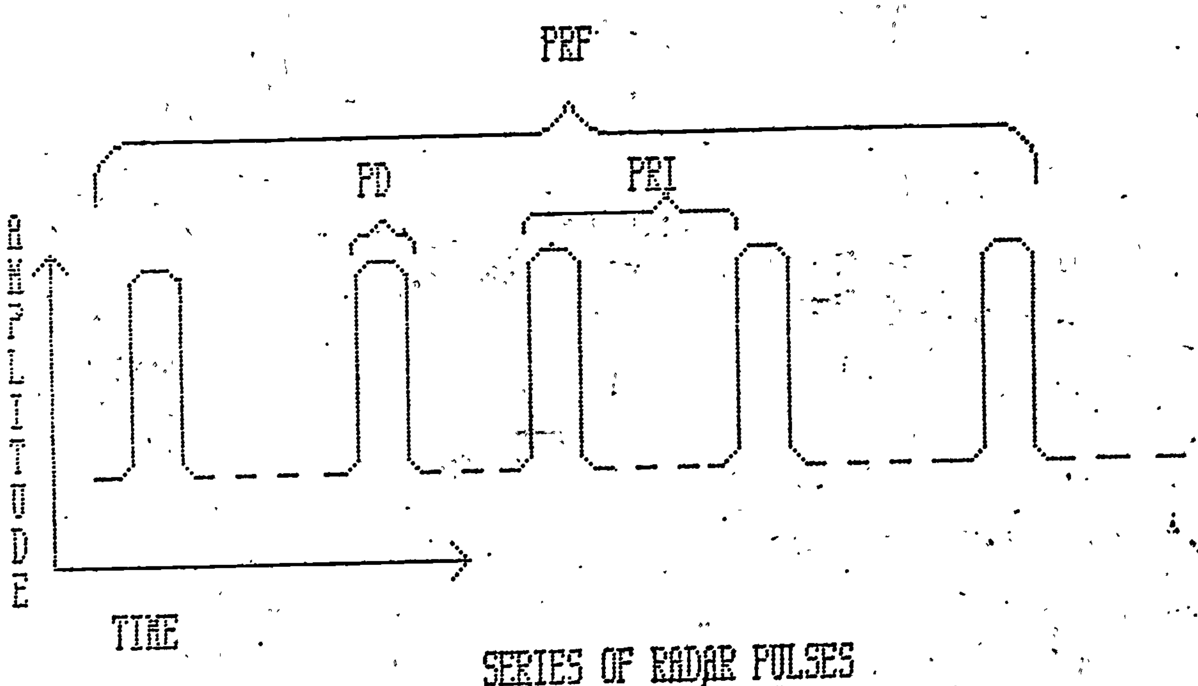

Figure 3. Sample of concept learning subject matter.

interval of approximately 1.5 seconds. Subjects were allowed a maximum of 30 seconds per page to acquire the concepts. Subjects were asked to read and learn each page of concept materials, because they would be tested shortly thereafter on their acquisition of basic radar notions. The concept materials consisted of 12 numbered study pages. The experimenter could synchronize the ERP recordings with a subject's acquisition of the concept learning materials by cuing on the large page numbers. The achievement test for concept learning consisted of ten five-alternative, multiple-choice, objectives-referenced items. Each item was scored one when correct and zero when incorrect. The total test score was simply the number of correct items. The basic pulsed-radar concepts administered to the subjects, together with their corresponding presentation pages and test items, are listed in Table 1.

Table 1

Test Item, Presentation Page Numbers, and Corresponding Concepts

Test Item	Presentation Page Numbers	Concept
1	1,2	Five basic components of radar
2	3,4	Pulse duration definition
3	5	Pulse repetition frequency (PRF) (definition)
4	5	PRF (measurement)
5	6	Pulse repetition interval (PRI) (definition)
6	6	PRI (measurement)
7	6	PRF/PRI relationship
8	7,8	Number of yards in a nautical mile
9	9,10	Number of yards a pulse travels in a microsecond
10	11,12	Radar range per microsecond

Statistical Analyses

Sixteen multiple regression analyses were computed employing as predictors the eight ERPs obtained per page of concepts and the ERPs derived across all concept pages. The criteria were the corresponding ten concept learning test items and the total achievement scores for all 56 subjects. Also, subjects were divided into two groups based upon whether their total concept achievement score was above or below the mean. Thirteen multiple discriminant analyses were computed for these defined groups using as input the ERPs recorded per page and those obtained across all pages of concepts.

RESULTS

The means and standard deviations for each item of the concept criterion test are presented in Table 2. Only one of the computed regression analyses employing ERP amplitudes for each page of concepts to predict corresponding test-item achievement was significant ($R = .55$, $R^2 = .30$, $SE = .45$, $F(8,47) = 2.55$, $p < .05$). This analysis involved ERPs recorded for presentation page 10 to predict performance on test item 9 dealing with the concept of how far a radar pulse travels in a microsecond. The means and standard deviations for the ERPs corresponding to this concept are given in Table 3. The standardized regression coefficients and their corresponding F-ratios indicated that the

Table 2

Means and Standard Deviations for Each Item of the Concept Criterion Test

Test Item	$\bar{X}$	SD
1	.71	.46
2	.41	.50
3	.38	.49
4	.14	.35
5	.39	.49
6	.16	.37
7	.54	.50
8	.64	.48
9	.61	.49
10	.61	.49

Note. N = 56.

Table 3

Means and Standard Deviations for ERPs Corresponding to Presentation Page 10 (Distance Radar Pulse Travels in a Microsecond)

Site	$\bar{X}$	SD
F3	2.65	1.05
T3	2.76	1.11
P3	3.14	1.05
O1	3.55	1.16
F4	2.94	1.23
T4	2.94	1.05
P4	3.24	1.09
O2	3.58	1.19

Note. N = 56.

significant predictors of test item 9 achievement were the ERPs recorded at the right temporal and parietal areas ($b = -.33$, $F(1,47) = 5.59$, $p < .05$; $b = .53$, $F(1,47) = 6.11$, $p < .05$ respectively). Corresponding product-moment correlations between ERPs recorded at the right temporal and parietal sites and test item 9 performance were $r(54) = -.38$, $p < .01$ and $r(54) = -.24$ respectively.

Statistics associated with the discriminant functions (eigenvalues, canonical correlations, Wilk's lambda, chi-squares, and group centroids respectively), using ERP amplitudes obtained for each page of concepts to separate the subjects below from those above the mean concept total score ($\bar{X}_c = 4.55$, $SD_c = 2.01$), revealed that three derived discriminant functions significantly distinguished between these two groups. These functions employed ERPs obtained during the learning of presentation pages 7, 8, and 11, which dealt with the concepts of how many yards in a nautical mile and radar range per microsecond respectively:

1. For page 7, $\lambda = .44$, $R_C = .55$, $\Lambda = .70$, $\chi^2(8) = 18.14$, $p = .02$, $C_b = .67$, $C_a = -.63$.
2. For page 8, $\lambda = .40$, $R_C = .53$, $\Lambda = .72$, $\chi^2(8) = 16.80$, $p = .03$, $C_b = .64$, $C_a = -.60$.
3. For page 11, $\lambda = .50$, $R_C = .58$, $\Lambda = .67$, $\chi^2(8) = 20.23$, $p = .01$, $C_b = .72$, $C_a = -.67$.

Standardized discriminant coefficients, univariate F-ratios, means, and standard deviations for each group were computed using ERP amplitudes corresponding to concepts on presentation pages 7, 8, and 11. In terms of the relative magnitudes of the discriminant coefficients, which reflect all the ERP amplitudes interacting together in a multivariate manner to separate the groups, the more important brain sites for contributing to the significant discriminant functions were:

1. For presentation page 7, the right temporal and occipital areas (d = 1.50, -1.54 respectively).

2. For presentation page 8, the right parietal region (d = 1.19).

3. For presentation page 11, the left and right parietal areas (d = 2.65, -3.0 respectively).

Taking each ERP alone (i.e., without it interacting in a multivariate fashion with others obtained per page of concepts), the univariate Fs and group means and standard deviations revealed that:

1. The right temporal ERP significantly differentiated the group below the mean total concept score from the group above the mean, with the group below the mean having the higher mean amplitude and larger standard deviation:

   a. For presentation page 7, $F(1,54) = 6.09$, $p = .02$, $\bar{X}_b = 3.48$, $\bar{X}_a = 2.71$, $SD_b = 1.40$, $SD_a = .90$.

   b. For presentation page 8, $F(1,54) = 5.46$, $p = .02$, $\bar{X}_b = 3.14$, $\bar{X}_a = 2.56$, $SD_b = 1.04$, $SD_a = .83$ respectively.

2. The right frontal ERP significantly differentiated the group below the mean total concept score from the group above the mean, with the group below the mean also having higher mean ERP amplitude and larger standard deviation:

   a. For presentation page 11, $F(1,54) = 5.97$, $p = .02$, $\bar{X}_b = 3.40$, $\bar{X}_a = 2.80$, $SD_b = 1.14$, $SD_a = 64$ respectively.

DISCUSSION AND CONCLUSIONS

The results established that some ERPs, recorded as students were in the process of learning concepts, seemed to be related to subsequent achievement. ERPs elicited at the right temporal and parietal areas appeared to be significantly associated with acquiring a concept—in this instance, the distance a radar pulse travels in a microsecond. Several ERPs were able to discriminate significantly below-average from above-average concept learners. Considering ERPs to interact statistically in a multivariate manner, ERPs evoked at the right temporal, parietal, and occipital and left parietal regions distinguished the below-average from above-average concept-learning group. Subsequently regarding ERPs singly, ERPs triggered at the right frontal and temporal areas significantly differentiated between the groups. At these two brain sites, the below-average concept learners had higher mean ERP amplitudes and larger standard deviations than did the above-average concept learners. The poorer concept learners appeared to engage the right frontal and temporal regions less and with greater variability than did the better learners, possibly because they processed less concept-related information at these brain locations. Theoretically, this study demonstrated that the right frontal, temporal, and parietal areas are significantly associated with concept learning--not only left hemisphere regions as proposed in the popular asymmetric model of the brain.

A few of the findings of this research, which used auditory stimuli to evoke ERPs, were somewhat consonant with Lewis and Rimland's (1976) results that right frontal and left parietal amplitudes elicited by visual stimuli were associated with predicting success in a Navy remedial reading program. Lewis, Rimland, and Callaway (1977) suggested that left parietal amplitudes triggered by visual stimuli are related to general aptitude and intelligence. These previous findings are only partially compatible with some of the results reported in this study since different stimuli were used to evoke cortical responses. Lewis and Froning (1981) demonstrated that the left parietal and right temporal areas discriminated between high and low reading groups using visual ERPs. Their investigation, together with the present study, indicated the importance of these sites for reading skill or comprehending concepts.

The research reported herein demonstrated the importance of the right frontal, temporal, parietal, and occipital regions together with the left parietal area for acquiring concepts. These results are like some of Federico, Froning, and Calder's (1983) findings regarding auditory ERPs, which revealed that the right frontal and temporal and left frontal regions are negatively related to reading skill and logical reasoning, based upon individual product-moment correlations. Also, the results of this study are similar to Lewis, Rimland, and Callaway's (1977) finding in that asymmetry at the parietal areas significantly distinguished between high and low general-aptitude groups. In this research, asymmetry measures were not derived; nevertheless, ERPs in the left and right parietal regions did contribute to the significant discrimination between below- and above-average concept learners. Molfese, Papanicolau, Hess, and Molfese (1979), however, identified components of the auditory evoked responses in the left and right temporal regions that were sensitive to semantic and conceptual processes. Also, Chapman (1977), using stimulus words that had been scaled according to the semantic differential technique (Osgood, Suci, & Tannenbaum, 1957) to evoke potentials recorded between brain sites Pz and Cz, provided evidence that two types of semantic properties could be independently identified in ERPs: (1) The semantic class of stimulus words (positive or negative evaluation, potency, or activity) and (2) the semantc dimension employed to judge stimulus words.

Many of the findings from this research on concept acquisition and brain electrical activity did not agree with the results of a number of other studies: right hemisphere ERP amplitudes appear to be positively related to intelligence (Bigum, Dustman, & Beck, 1970; Galbraith, Gliddon, & Busk, 1970; Perry, McCoy, Cunningham, Falgout, & Street, 1976; Rhodes, Dustman, & Beck, 1969; Richlin, Weisinger, Weinstein, Giannini, & Morganstern, 1971; Shucard & Horn, 1973). In this investigation, auditory ERPs elicited at the right frontal, temporal, and parietal areas were found to be negatively related to concept learning--which is obviously associated with intelligence.

Unlike the study by Federico, Froning, and Calder (1983), ERPs reported herein were recorded while subjects were actually engaged in a concept acquisition task. Each subject's involvement in the learning task had been adequately motivated and closely monitored to assure his continuous cognitive processing of the textual information presented during the ERP recording session. During this period, irrelevant auditory tones were superimposed upon ongoing prose processing. Possibly, the right hemisphere sites involved were more engaged or activated by the processing requirements of the concept learning task and superimposed auditory probes than they were by the separate processing of only visual or auditory stimuli used by Federico, Froning, and Calder (1983) to elicit ERPs. It seems that this speculation would have been especially true for above-average concept learners. This could have produced the pattern of significant and negative correlations obtained between concept-learning performance and ERPs evoked at right hemishpere sites.

It should be noted, however, that Shucard, Shucard, and Thomas (1977) found that the left temporal region responded with lower ERP amplitude than did the corresponding right to irrelevant auditory probes while subjects were engaged in a verbal processing task. They speculated that, in the engaged hemisphere, fewer neurons would probably be available to respond to the probe stimulus. Consequently, this would have produced a low amplitude ERP at the involved hemispheric site. The findings presented here and those of others (e.g., Doyle, Ornstein, & Galin, 1974; Galin & Ellis, 1975; Galin & Ornstein, 1972; Shucard, Shucard, & Thomas, 1977) further substantiate the hypothesis that brain hemispheres can respond intermittently and function independently of one another.

The findings presented herein:

1. Suggest that ERP procedures can be used to study the relationship between electrical activity in the brain and human cognition.

2. Establish some ERP correlates of concept learning.

3. Imply that some ERPs reflect individual differences in conceptual function.

RECOMMENDATION

Even though this study established that some ERPs are significantly correlated with concept learning, the number and strength of the relationships were not of sufficient magnitude to warrant the practical application of ERPs as a basis for the development of adaptive instructional strategies for Navy training.

REFERENCES

Barnet, A. B. EEG and evoked response correlates of mental retardation. Clinical proceedings of the children's hospital, 1971, 27, 250-260.

Barnet, A. B., & Lodge, A. Click evoked EEG responses in normal and developmentally retarded infants. Nature, 1967 214, 252-255.

Bennett, W. F. Human perception: A network theory approach. Nature, 1968, 220, 1147-1148.

Bigum, H. B., Dustman, R. F., & Beck, E. C. Visual and somato-sensory evoked responses from mongoloid and normal children. Electroencephalography and Clinical Neurophysiology, 1970, 28, 576-585.

Bogen, J. E. The other side of the brain, I, II, III. Bulletin of the Los Angeles Neurological Society, 1969, 34, 73-105, 135-162, 191-220.

Buchsbaum, M., & Silverman, J. Averaged evoked response and perception of the vertical. Journal of Experimental Research in Personality, 1970, 4, 79-83.

Callaway, E. Correlations between averaged evoked potentials and measures of intelligence. Archives of General Psychiatry, 1973, 29, 553-558.

Callaway, E. Brain electrical potentials and individual psychological differences. New York: Grune & Stratton, 1975.

Callaway, E., & Stone, G. C. Evoked response methods for the study of intelligence. Agressologie, 1969, 10(special number), 535-539.

Chalke, F. C. R., & Ertl, J. P. Evoked potentials and intelligence. Life Sciences, 1965, 4, 1319-1322.

Chapman, R. Connotative meaning and averaged evoked potentials. In H. Begleiter (Ed.), Evoked brain potentials and behavior. New York: Plenum Press, 1977.

Cronbach, L. J., & Snow, R. E. Aptitude and instructional methods: A handbook for research on interactions. New York: Irvington, 1977.

Dimond, S. J., & Beaumont, J. G. (Eds.). Hemisphere function in the human brain. New York: Wiley, 1974.

Donchin, E. On evoked potentials, cognition, and memory. Science, 1975, 190(4218), 1004-1005.

Donchin, E., & Cohen, L. Averaged evoked potentials and intramodality selective attention. Electroencephalography and Clinical Neurophysiology, 1967 22(6), 537-546.

Donchin, E., Kubovy, M., Kutas, M., Johnson, R. & Hering, R. Graded changes in evoked response (P300) amplitude as a function of cognitive activity. Perception and Psychophysics, 1973, 14(2), 319-324.

Doyle, J. C., Ornstein, R., & Galin, D. Lateral specializtion of cognitive mode: II. EEG frequency analysis. Psychophysiology, 1974, 11(5), 567-578.

Engel, R., & Fay, W. Visual evoked responses at birth, verbal scores at three years, and IQ at four years. Developmental Medicine and Child Neurology, 1972, 14, 283-289.

Ertl, J. Evoked potentials, neural efficiency, and IQ. In L. D. Proctor (Ed.), Biocybernetics of the central nervous system. Boston: Little and Brow, 1969.

Ertl, J. P. Fourier analysis of evoked potentials and human intelligence. Nature, 1971, 230, 525-526.

Ertl, J. P. IQ evoked responses and Fourier analysis. Nature, 1973, 241, 209-210.

Ertl, J. P., & Schafer, E. W. P. Brain response correlates of psychometric intelligence. Nature, 1969, 223, 421-422.

Federico, P-A. Accommodating instruction to student characteristics: Trends and issues (NPRDC Tech. Rep. 79-1). San Diego: Navy Personnel Research and Development Center, October 1978. (AD-A060 587)

Federico, P-A. Adaptive instruction: Trends and issues. In R. E. Snow, P-A Federico, and W. E. Montague (Eds.), Conference proceedings: Aptitude, learning, and instruction, Volume I. Cognitive process analyses of aptitude (NPRDC/ONR Tech. Rep. 81-5). San Diego: Navy Personnel Research and Development Center, January 1981. (AD-A099 209)

Federico, P-A., & Landis, D. B. Discriminating between failures and graduates in a computer-managed course using measures of cognitive styles, abilities, and aptitudes (NPRDC Tech. Rep. 79-21). San Diego: Navy Personnel Research and Development Center, June 1979. (a) (AD-A070 748)

Federico, P-A., & Landis, D. B. Predicting student performance in a computer-managed course using measures of cognitive styles, abilities, and aptitudes (NPRDC Tech. Rep. 79-30). San Diego: Navy Personnel Research and Development Center, August 1979. (b) (AD-A074 880)

Federico, P-A., & Landis, D. B. Relationships among selected measures of cognitive styles, abilities, and aptitudes (NPRDC Tech. Rep. 80-23). San Diego: Navy Personnel Research and Development Center, April 1980. (AD-A090 729)

Federico, P-A., Froning, J. N., & Calder, M. Validation of brain event-related potentials as indicators of cognitive styles, abilities, and aptitudes (NPRDC Tech. Rep. 83-11). San Diego: Navy Personnel Research and Development Center, February 1983.

Friedman, M., Guyer-Christie, B., & Tymchuk, A. Cognitive style and specialized hemispheric processing in learning disability. In R. Knights and D. Bakker (Eds.), The neuropsychology of learning disorders: Theoretical approaches. Baltimore: University Park Press, 1976.

Galbraith, G. C., Gliddon, J. B., & Busk, J. Visual evoked responses in mentally retarded and nonretarded subjects. American Journal of Mental Deficiency, 1970, 75, 341-348.

Galin, D., & Ellis, R. R. Asymmetry in evoked potentials as an index of laterized cognitive processes: Relation to EEG alpha asymmetry. Neuropsychologia, 1975, 13, 45-50.

Galin, D., & Ornstein, R. Lateral specialization of cognitive mode: An EEG study. Psychophysiology, 1972, 9, 412-418.

Gucker, D. K. Correlating visual evoked potentials with psychometric intelligence, variation in techinique. Perceptual and Motor Skills, 1973, 37, 189-190.

Henderson, N. B., & Engel, R. Neo-natal visual evoked potentials as predictors of psychoeducational tests at age seven. Developmental Psychology, 1974, 10, 269-276.

Horst, R. L., Johnson, R., & Donchin, E. Event-related brain potentials and subjective probability in a learning task. Memory and Cognition, 1980, 8(5), 476-488.

Israel, J., Chesney, G., Wickens, C., & Donchin, E. P300 and tracking difficulty: Evidence for multiple resources in dual-task performance. Psychophysiology, 1980, 17(3), 259-273.

Israel, J., Wickens, C., Chesney, G., & Donchin, E. The event-related potential as an index of display-monitoring workload. Human Factors, 1980, 22(2), 211-224.

Jasper, H. The ten-twenty electrode system of the international federation. Electroencephalography and clinical neurophysiology, 1958, 10, 371-375.

Kinsbourne, M. (Ed.). Asymmetrical function of the brain. New York: Cambridge University Press, 1978.

Knights, R. M., & Bakker, D. J. The neuropsychology of learning disorders: Theoretical approaches. Baltimore: University Park Press, 1976.

Lewis, G. W. Visual event related potentials of pilots and navigators. In D. Lehmann, & E. Callaway (Eds.), Human evoked potentials: Applications and problems. New York: Plenum Press, 1979.

Lewis, G. W. Job performance and brain asymmetry: Relevance for physical security personnel. Presented at the Fifth Annual Meeting on the Role of Behavior Science in Physical Security, held 11-12 June 1980 at the National Bureau of Standards, Gaithersburg, Maryland.

Lewis, G. W., Federico, P-A., Froning, J. N., & Calder, M. Event-related brain potentials and cognitive processing: Implications for Navy training. (NPRDC Tech. Rep. 82-8). San Diego: Navy Personnel Research and Development Center, October 1981. (AD-A109 019)

Lewis, G. W., & Froning, J. N. Sensory interaction, brain activity, and reading ability in young adults. International Journal of Neuroscience, 1981, 15, 129-140.

Lewis, G. W., & Rimland, B. Psychobiological predictors of success in a Navy remedial reading program (NPRDC Tech. Rep. 77-13). San Diego: Navy Personnel Research and Development Center, December 1976. (AD-A037 339)

Lewis, G. W., & Rimland, B. Hemispheric asymmetry as related to pilot and radar intercept officer performance (NPRDC Tech. Rep. 79-13). San Diego: Navy Personnel Research and Development Center, March 1979. (AD-A068 087)

Lewis, G. W., & Rimland, B. Psychobiological measures as predictors of sonar operator performance (NPRDC Tech. Rep. 80-26). San Diego: Navy Personnel Research and Development Center, May 1980. (AD-A085 030)

Lewis, G. W., Rimland, B., & Callaway, E. Psychobiological correlates of aptitude among Navy recruits (NPRDC Tech. Note 77-7). San Diego: Navy Personnel Research and Development Center, February 1977.

Marcus, M. M. The evoked cortical response: A technique for assessing development. California Mental Health Research Digest, 1970, 8, 59-72.

Molfese, D., Papanicolau, A., Hess, T, & Molfese, V. Neuroelectrical correlates of semantic processes. In H. Begleiter (Ed.), Evoked brain potentals and behavior. New York: Plenum Press, 1979.

Ornstein, R. E. The psychology of consciousness (2nd Ed.). New York: Harcourt Brace Jovanovice, Inc., 1977.

Osborne, R. T. Heritability estimates for the visual evoked response. Life Sciences, 1970, 9, 481-490.

Osgood, C. E., Suci, G. J., Tannenbaum, P. H. The measurement of meaning. Urbana, IL: University of Illinois, 1957.

Perry, N. W., McCoy, J. G., Cunningham, W. R., Falgout, J. C., & Street, W. J. Multivariate visual evoked response correlates of intelligence. Psychophysiology, 1976, 13, 323-329.

Pizzamiglio, L. Cognitive approach to hemispheric dominance. In R. Knights and D. Bakker (Eds.), The neuropsychology of learning disorders: Theoretical approaches. Baltimore: University Park Press, 1976.

Ray, W., Morell, M., Frediani, A., & Tucker, D. Sex differences and lateral specialization of hemispheric functioning. Neuropsychologia, 1976, 14(3), 391-394.

Rhodes, L. E., Dustman, R. E., & Beck, E. C. The visual evoked response: A comparison of bright and dull children. Electroencephalography and Clinical Neurophysiology, 1969, 27, 364-372.

Richlin, M., Weisinger, M., Weinstein, S., Giannini, M., & Morganstern, M. Interhemispheric asymmetries of evoked cortical responses on retarded and normal children. Cortex, 1971, 1, 98-105.

Shearer, S., & Tucker, D. Differential cognitive contributions of the cerebral hemispheres in the modulation of emotional arousal. Cognitive Therapy and Research, 1981, 5(1), 85-91.

Shucard, D. W., & Callaway, E. Auditory evoked potential amplitude and variability effects of task and intellectual ability. Journal of Comparative and Physiological Psychology, 1974, 87, 284-294.

Shucard, D. W., & Horn, J. L. Evoked cortical potentials and measurement of human abilities. Journal of Comparative and Physiological Psychology, 1972, 78, 59-68.

Shucard, D. W., & Horn, J. L. Evoked potential amplitude change related to intelligence and arousal. Psychophysiology, 1973, 10, 445-452.

Shucard, D., Shucard, J., & Thomas, D. Auditory evoked potentials as probes of hemispheric differences in cognitive processing. Science, 1977, 197, 1295-1298.

Squires, K., Petuchowski, S., Wickens, C., & Donchin, E. The effect of stimulus sequence on event related potentials: A comparison of visual and auditory sequences. Perception and Psychophysics, 1977, 22(1), 31-40

Tucker, D. M. Lateral brain function, emotion, and conceptualization. Psychological Bulletin, 1981, 89(1), 19-46.

Tucker, D., Shearer, S., & Murray, D. Hemispheric specialization and cognitive behavior therapy. Cognitive Therapy and Research, 1977, 1(4), 263-273.

Weinberg, H. Correlation of frequency spectra of averaged visual evoked potentials and verbal intelligence. Nature, 1969, 224, 813-815.

Wickens, C., Mountford, S., & Schreiner, W. Multiple resources, task-hemispheric integrity, and individual differences in time-sharing. Human Factors, 1981, 23(2), 211-229.

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