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**TEMPORAL STABILITY OF MULTICHANNEL,  
MULTIMODAL ERP RECORDINGS**

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**NAVY PERSONNEL RESEARCH  
AND  
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**TEMPORAL STABILITY OF MULTICHANNEL, MULTIMODAL ERP RECORDINGS**

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## FOREWORD

This report, which was originally published in the International Journal of Neuroscience in 1984, is being reprinted by the Navy Personnel Research and Development Center to provide wider distribution. It was supported by the Defense Nuclear Agency and the Department of the Navy.

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## SUMMARY

Prior research has suggested that brain electrical recordings, such as the event-related potential (ERP), may substantially augment personnel assessment procedures. Such assessment includes selection and classification of individuals for specific jobs, determination of stress tolerance, and prediction of on-job performance. Fundamental to using the ERP for these purposes is determining its sensitivity to individual differences and the long-term stability or reliability of specific ERP measures. Stability refers to the repeatability or similarity in the ERP waveform across time. The usual procedure followed for determining stability is computing the correlation coefficient between two waveforms. High correlation between waveforms suggests similarity, while low correlation suggests variability.

In this study, visual, auditory, and bimodal ERP records were obtained about two hours apart from a group of young adult males. Similar records were obtained about two months apart from a group of older adults. No ERP amplitude or temporal stability differences were found between the two groups. Age was positively correlated with visual stability measures and negatively correlated with auditory stability measures. No correlation of age with bimodal stability measures was found. Large individual subject differences were found for the ERP analog waveform and temporal stability. The ERPs were highly stable within subjects from session to session, whether recorded hours or months apart. Greatest stability was obtained for bimodal presentation, less for visual, and least for the auditory records. Differences in patterns of waveform stability were found for site and modality conditions across individuals.

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# TEMPORAL STABILITY OF MULTICHANNEL, MULTIMODAL ERP RECORDINGS

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*(Received June 25, 1984)*

Personnel assessment applications of event related brain potentials (ERP) require temporal stability. Visual, auditory and bimodal ERP records were obtained about two hours apart for a group of young adult males. Similar records were obtained from a group of older adults about two months apart. No ERP amplitude or temporal stability differences were found between the two groups. Age was positively correlated with visual stability measures and negatively correlated with auditory stability measures. No correlation of age with bimodal stability measures was found. Large individual subject differences were found for the ERP analog waveform and temporal stability. The ERPs were highly stable within subjects from session to session, whether recorded hours or months apart. Greatest stability was obtained for bimodal presentation, less for visual and least for the auditory records. Differences in patterns of waveform stability were found for site and modality conditions across individuals.

Earlier research has suggested that brain electrical recordings, such as the event related potential (ERP), may substantially augment personnel assessment procedures currently in use (Lewis, 1983). Such assessment includes selection and classification of individuals for specific jobs, determining stress tolerance, and predicting on-job performance. Fundamental to using the ERP for these purposes is determining the sensitivity to individual differences and the long-term stability or reliability of specific ERP measures. Stability refers to the repeatability or similarity in the ERP waveform across time. The usual procedure followed for determining stability is computing the correlation coefficient between two waveforms and has been discussed by Glaser and Ruchkin (1976). High correlation between waveforms suggests similarity, while low correlation suggests variability.

Early papers by Travis and Gottlob (1936, 1937), Davis and Davis (1936), Rubin (1938) and Williams (1939) suggested that EEG activity showed individuality and were stable from day to day. Such activity patterns were shown to be not only stable and show individuality, but also that they were inherited (Lennox, Gibbs, & Gibbs, 1945). More recently, several studies have found stable EEG records within subjects (Matousek, Arvidsson, & Friberg, 1979; Van Dis, Corner, Dapper, Hanewald, & Kok, 1979; Stassen, 1980; Fein, Galin, Johnstone, Yingling, Marcus, & Kiersch, 1983). Research has also demonstrated that EEG and stimulus-locked EEG records (ERP) were very sensitive to individual differences (Henry, 1941, (a) & (b); Brazier, 1962; Uttal & Cook, 1964; Werre & Smith, 1964; Berkhout & Walter, 1968; Buchsbaum & Pfefferbaum, 1971; Callaway, 1975; and Lewis, 1983). Early research relating more variable, state-like attributes to psychological aspects were described by Travis (1937),

Travis and Egan (1938), Hoaglund, Cameron, Rubin, and Tegelberg (1938), Knott (1938) and Hadley (1940, 1941).

With the advent of signal averaging techniques (i.e., ERP) and instrumentation, tighter stimulus-response observations were made available. Sensory systems (i.e., visual, auditory, somatosensory) as well as higher order cognitive processing and psychological variables could be explored in greater detail. Much variability in ERP recordings has been noted between and within subjects. ERP variability, its contributing factors, and relationships to cognitive variability have been discussed by Callaway (1975). Greater ERP variability has been noted in psychopathology patients (Callaway, Jones, & Donchin, 1970; Shagass, 1972; Cohen, 1972; Callaway, 1975; Buchsbaum & Coppola, 1977) and newborn infants (Ellingson, 1970) than normal adults. Dustman & Beck (1969) described the stabilizing of visual ERP amplitude with maturity at about age 16. Ellingson, Lathrop, Danahy, & Nelson (1973), studying adults and infants, found greater visual evoked potential stability within sessions than over days; and adults showed greater stability than did the infants. These authors used the Pearson product-moment correlation on the 500 msec visual evoked potential (128 data points) for their stability measure.

Stability of evoked activity has been examined for the visual modality (Dustman & Beck, 1963; Kooi & Bagchi, 1964; Wicke, Donchin & Lindsay, 1964); the auditory modality (Buchsbaum, Henkin, & Christiansen, 1974; Ellingson, Danahy, Nelson, & Lathrop, 1974); and a comparison of visual and auditory modalities (Buchsbaum & Coppola, 1977). Results have shown high intrasubject and low intersubject stability. For the visual modality, greatest stability has been found in the occipital and central regions (Kooi & Bagchi, 1964). Greatest auditory evoked potential stability has been found for children (6-9 years) and least for older (40-60 years) adults (Buchsbaum *et al.*, 1974). Comparison of visual and auditory records showed greater stability for visual than auditory (Buchsbaum & Coppola, 1977). Their area-under-curve measures showed greater stability than baseline-to-peak measures for records obtained two or more weeks apart.

Much of the personnel assessment done by the Navy deals with enlisted recruits. In this Center's laboratory, most data recording has been restricted to a single three-hour session using primarily young adult male subjects. Even though these subject and recording conditions are adequate for on-going projects, extending the ERP measures to older subjects and recording over a longer period of time is essential to generalize ERP technology to wider applications of personnel assessment.

Nearly all ERP waveform stability research has been restricted to one or two data channels obtained from visual and auditory stimuli. Earlier research in our laboratory has shown the value of relating bimodal ERP measures, in addition to visual and auditory ERP measures, to sensory interaction, reading ability, and cognitive style. The purpose of the current research is to describe ERP stability relationships for two groups of subjects: one of young adults (recruits) for whom recording sessions were about two hours apart, and a second, of older adults with recording sessions about two months apart. Stability measurements will be described for visual and auditory ERP records. Earlier research in this and other laboratories (Lewis, 1983; Lewis & Froning, 1981; Shipley, 1970, 1980; Shipley & Jones, 1969; Shipley & Hyson, 1977) has suggested the importance of bimodal recording from remedial reader and control subjects. Stability measurements will be extended to the bimodal ERP, simultaneous presentation of visual and auditory stimuli from eight sites (F3, F4, T3, T4, P3, P4, O1, O2). Relationships between age and stability measures also will be described.



## TEMPORAL STABILITY OF ERP RECORDS

### METHOD

#### *Instrumentation*

Data recordings were obtained using a Data General NOVA 2/10 computer equipped with a three-drive floppy disk unit (Advanced Electronics Design Inc., Model 2500), high resolution oscilloscope monitor (Tektronix, Model 603), and EEG amplifiers (Grass Model P511J) with band-pass set for 0.1–100 Hz and total gain of 20,000 X. Subject protection was provided by placing the entire computer data acquisition system on a heavy duty ultra-isolation and medically calibrated ( $<10 \mu\text{A}$ ) transformer (Topaz, 2.5 KW). A video terminal (Advanced Electronics Design, Inc., Model AED 512) was used to present visual stimuli and later display the data off-line.

#### *Stimuli*

Visual stimuli were computer generated black and white checker-board patterns presented over the video monitor (Panasonic 14-inch Model WV 5400). Binocular visual field stimulation was about 9 degrees visual angle. Each check subtended about 17 minutes visual angle. Average background luminance was about 0.4 foot-Lamberts (ftL), while average target luminance was about 5 ftL (Gamma Scientific Telephotometer System, Model 2009K). The patterns of 2 msec duration were presented aperiodically averaging about 2 sec interestimulus interval (1.0–3.0 sec).

Auditory clicks of 2 msec duration were presented binaurally over headphones (Sennheiser Model 424X) aperiodically about every 2 sec (1.0–3.0 sec). 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.

Bimodal presentation included simultaneous presentation of the visual and auditory stimuli. These stimuli were presented aperiodically about every 2 sec (1.0–3.0 sec). During all recording periods, white noise was presented to the subject through the headphones and via a speaker in the sound chamber (approximately 50 dB (A)). The visual, auditory and bimodal stimuli were presented sequentially (20 stimuli per average). The stimulus sequence was randomized for each subject.

#### *Procedures*

Procedures following Lewis and Froning, (1981) and Lewis (1983) were used. After instructions were given and the consent form signed, each subject was fitted with a lycra helmet having electrodes placed at homologous sites in the frontal (F3, F4), temporal (T3, T4), parietal (P3, P4), and occipital (O1, O2) regions. All sites were referenced to nose. Subject ground was at Pz. Electrode impedance did not exceed 3K ohms. Artifacts were monitored and rejected through computerized eye-movement detection, a switch used by the subject if he had to move, and on-line rejection by the operator at the console. All recording was performed inside an IAC sound chamber.

After recordings were obtained, the data were displayed on the video monitor and a hard copy obtained.

Figure 1 shows sample data. All ERP records were 512 msec poststimulus and were averaged over 20 stimuli. Prestimulus records were also obtained, but not reported in this paper. Calibration, polarity, and time base information are displayed. Post-

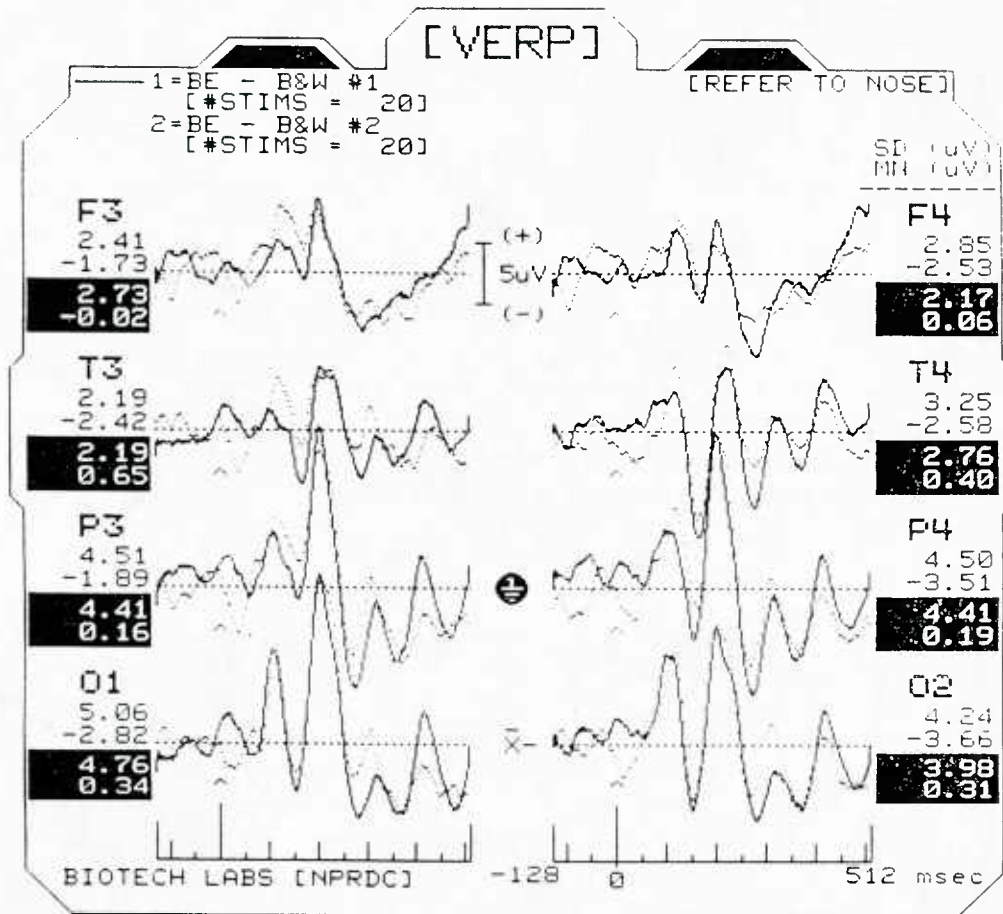


FIGURE 1 Sample visual ERP data from one subject, two sessions. Records from the first session in solid lines, those from the second in dotted lines. Data obtained two hours apart.

stimulus waveform amplitude (standard deviation,  $SD_{\mu V}$ ) and mean ( $MN_{\mu V}$ ) values were computed and displayed for each subject's electrode site. The waveforms in the left and right columns were derived from the left and right hemispheres respectively. From top to bottom, the records are from: frontal, temporal, parietal and occipital regions. The stability, or test-retest reliability of the ERP waveforms, was measured by computing the point-by-point correlations of the poststimulus waveforms. A total of 256 points (addresses) was used for each 512 msec period (2 msec per address sampling time).

### Subjects

Two groups of subjects were examined. Group A ( $N=8$ ) comprised right-handed enlisted males undergoing basic training. Due to their training schedule, it was not possible to record data on successive days. Data recording sessions were about two hours apart. Age at testing was  $19.6 \pm 0.9$  years. Group B ( $N=8$ ) comprised experienced laboratory personnel. Recordings were made about 2 months apart. Age of this group was  $33.1 \pm 9.6$  years. One subject was female (No. 20), another was left-handed (No. 24). All other subjects were right-handed males.

# TEMPORAL STABILITY OF ERP RECORDS

## RESULTS

The issue of independence of sampling and degrees of freedom (*df*) deserves comment. Waveform correlations were based on 256 data points per waveform. These data points were not independent within or across records as they were obtained from the same individual. Likewise, recording sites across the scalp were correlated, also violating the statistical assumption of sampling independence. Multiple *t*-tests or correlations produce inflated probability levels. The Bonferroni approach (Harris, 1975) addresses this issue (inflated Type I error, probability of falsely rejecting the null hypothesis). For purposes of statistical testing in this paper, a conservative approach to determining *df* was made. The number of subjects in each of the two groups (source of true sampling independence) was used to determine *df* ( $8-1 = 7$  *df*).

To assess the effects of age and time between recording session differences between the two groups, separate *t*-tests were performed for visual, auditory and bimodal ERP amplitudes. No statistically significant differences in amplitudes were found between the two groups for any of the eight recording sites, either of the two recording sessions or three stimuli presentations.

TABLE I  
Temporal stability cross-correlations for visual ERP records session 1 versus 2

Subject	Left Hemisphere				Right Hemisphere			
	F3	T3	P3	O1	F4	T4	P4	O2
Group A								
7 <sup>a</sup>	0.73	0.81	0.88	0.90	0.63	0.73	0.82	0.88
8	0.68	0.57	0.80	0.80	0.44	0.56	0.78	0.81
9	0.54	0.73	0.76	0.61	0.43	0.45	0.59	0.67
10	0.48	0.22	0.37	0.65	0.58	0.69	0.56	0.65
11	0.57	0.40	0.53	0.38	0.62	0.31	0.61	0.65
13	0.15	0.70	0.75	0.62	0.00	0.75	0.78	0.75
14	0.72	0.42	0.68	0.91	0.76	0.19	0.53	0.89
15	-0.17	-0.19	0.30	0.67	0.05	0.68	0.58	0.75
MN	0.46	0.46	0.63	0.69	0.44	0.55	0.66	0.76
SD	0.32	0.33	0.21	0.18	0.28	0.21	0.12	0.10
Group B								
16 <sup>b</sup>	0.27	0.84	0.83	0.90	0.18	0.66	0.80	0.90
17	0.30	0.07	0.21	0.50	0.09	0.16	0.46	0.58
18	0.24	0.28	0.40	0.87	0.63	0.75	0.67	0.88
19	0.79	0.19	0.13	0.73	0.80	0.38	0.21	0.74
20 <sup>c</sup>	0.32	0.34	0.50	0.69	-0.04	0.49	0.51	0.72
21	0.23	0.27	0.27	0.89	0.30	0.67	0.54	0.93
22	0.78	0.92	0.90	0.86	0.76	0.86	0.90	0.83
24	0.47	0.84	0.75	0.91	0.49	0.44	0.71	0.91
MN	0.43	0.47	0.50	0.79	0.40	0.55	0.60	0.81
SD	0.23	0.34	0.30	0.14	0.32	0.23	0.22	0.12

*df* = 7

*p* < 0.01 = 0.80

*p* < 0.05 = 0.67

<sup>a</sup>Subjects 7-15 NTC Recruits, sessions ca. 2 hours apart

<sup>b</sup>Subjects 16-24 NPRDC Employees, sessions ca. 2 months apart

<sup>c</sup>Female

Even though the two groups could be combined (*t*-tests not statistically significant), the correlations across sessions (stability measures) were reported separately (Tables I to III).

Stability measures for visual ERP waveforms from each subject and site appear in Table I. Large individual subject differences in stability were observed, as well as large differences between sites. The mean correlation values increased from the frontal to the occipital sites for both groups and hemispheres. Mean value for all correlations in Table I was 0.58. Most of the statistically significant values were found at the occipital sites. Group B showed higher and greater number of significant correlations from the occipital sites than did Group A. From a total of 128 measures, for both groups, 60 (47%) were significant at the  $p < 0.05$  level, and of these, 29 reached the  $p < 0.01$  level of statistical significance.

Auditory waveform stability data appear in Table II. Most stable waveforms (highest correlations) were found in the frontal and temporal regions. Group A showed highest correlations at the T3 and T4 sites, while those for Group B were at the F3 and F4 sites. Lowest correlations were obtained from the O1 and O2 sites for both groups. Overall mean correlation values were less for auditory (0.45) than for visual waveforms (0.58). Fewer auditory values reached statistical significance than were found for the visual records; 35 reached  $p < 0.05$  which included 10 that reached the  $p < 0.01$  level.

TABLE II  
Temporal stability cross-correlations for auditory ERP records session 1 versus 2

Subject	Left Hemisphere				Right Hemisphere			
	F3	T3	P3	O1	F4	T4	P4	O2
Group A								
7	0.74	0.75	0.77	0.55	0.53	0.72	0.65	0.40
8	0.29	0.68	0.34	0.31	0.32	0.55	0.46	0.45
9	0.03	0.79	0.85	0.62	-0.01	0.46	0.62	0.43
10	0.63	0.72	0.74	0.20	0.56	0.52	0.61	0.26
11	0.73	0.61	0.72	0.48	0.67	0.84	0.82	0.54
13	0.20	0.84	0.74	0.59	0.26	0.81	0.73	0.49
14	0.37	0.56	0.42	0.06	0.51	0.64	0.18	-0.02
15	0.62	0.19	0.29	-0.43	0.48	0.72	0.13	0.16
MN	0.45	0.64	0.61	0.30	0.42	0.66	0.53	0.34
SD	0.27	0.20	0.22	0.36	0.22	0.14	0.25	0.19
Group B								
16	0.77	0.06	0.65	0.22	0.78	0.22	-0.02	0.04
17	0.59	0.19	0.13	-0.14	0.55	0.45	0.33	-0.04
18	0.60	0.31	0.19	-0.15	0.52	0.42	0.16	-0.21
19	0.54	0.77	0.26	0.30	0.26	0.12	0.27	0.13
20	0.42	0.79	0.79	0.55	0.23	0.81	0.79	0.58
21	0.91	0.70	0.79	0.68	0.91	0.78	0.70	0.54
22	0.65	0.30	0.13	0.10	0.55	0.51	0.23	0.21
24	0.80	0.25	0.47	0.22	0.83	0.43	0.41	0.11
MN	0.66	0.42	0.43	0.22	0.58	0.47	0.36	0.17
SD	0.16	0.29	0.29	0.30	0.25	0.24	0.27	0.27



# TEMPORAL STABILITY OF ERP RECORDS

Bimodal stability measures are presented in Table III. A greater number of bimodal measures reached statistical significance than for either visual (60) or auditory (35) records. A total of 88 measures reached the  $p < 0.05$  level of statistical significance. Of these, 51 reached the  $p < 0.01$  level. All occipital sites (16) for the B group reached the  $p < 0.05$  level; 13 of 16 reached the  $p < 0.01$  level. For Group A, 12 reached  $p < 0.05$  and 11 reached the  $p < 0.01$  level of significance. The two groups had about the same number of statistically significant correlations for the frontal, temporal and parietal sites; 31 of 48 measures reached the  $p < 0.05$  significance level for Group A, while 26 of 48 were found for Group B.

Analysis of variance (ANOVA) was run on the stability measures to assess groups (A, B), stimuli (visual, auditory, bimodal), hemisphere (left, right) and site (frontal, temporal, parietal, occipital) main effects and interactions. Only the main effect for stimulus was statistically significant ( $F = 15.02$ ,  $p < 0.01$ ,  $df = 1, 14$ ). Instead of hypothesis testing with the usual  $df = 2, 28$ , a more conservative test was made using  $df = 1, 14$ .

The mean correlation values for visual (0.58) and auditory (0.45) records were less (less stable) than for the bimodal records (0.70). Stimulus-by-site interaction was also significant ( $F = 13.89$ ,  $p < 0.01$ ,  $df = 1, 14$ ). The  $df = 1, 14$  was used instead of 6, 84 for a more conservative  $F$ -test interpretation. Mean values for this interaction are plotted in Figure 2. From this figure, it may be seen that the stability values for the bimodal presentation were greater for all sites than for either visual or auditory conditions. Greatest stability was observed at the occipital site during bimodal presentation.

TABLE III  
Temporal stability cross-correlations for bimodal ERP records session 1 versus 2

Subjects	Left Hemisphere				Right Hemisphere			
	F3	T3	P3	O1	F4	T4	P4	O2
Group A								
7	0.81	0.82	0.91	0.91	0.80	0.79	0.89	0.86
8	0.67	0.78	0.76	0.81	0.51	0.44	0.71	0.82
9	0.70	0.59	0.79	0.61	0.75	0.48	0.58	0.43
10	0.91	0.33	0.62	0.83	0.87	0.77	0.70	0.70
11	0.75	0.70	0.81	0.83	0.76	0.71	0.81	0.92
13	0.48	0.89	0.87	0.87	0.22	0.58	0.72	0.91
14	0.55	0.87	0.86	0.87	0.67	0.82	0.81	0.84
15	0.52	0.32	0.62	0.41	0.52	0.70	0.47	0.48
MN	0.67	0.66	0.78	0.77	0.64	0.66	0.71	0.75
SD	0.15	0.23	0.11	0.17	0.21	0.14	0.13	0.19
Group B								
16	0.68	0.79	0.88	0.95	0.74	0.82	0.83	0.90
17	0.66	0.46	0.66	0.86	0.59	0.36	0.65	0.84
18	0.10	0.29	0.26	0.72	0.17	0.52	0.27	0.69
19	0.72	0.68	0.59	0.86	0.68	0.00	0.44	0.80
20	0.68	0.77	0.81	0.85	0.60	0.77	0.76	0.76
21	0.85	0.56	0.55	0.85	0.73	0.37	0.46	0.92
22	0.56	0.74	0.85	0.94	0.57	0.67	0.90	0.90
24	0.87	0.80	0.87	0.97	0.90	0.79	0.92	0.97
MN	0.64	0.64	0.68	0.88	0.62	0.54	0.65	0.85
SD	0.24	0.18	0.22	0.08	0.22	0.28	0.24	0.09

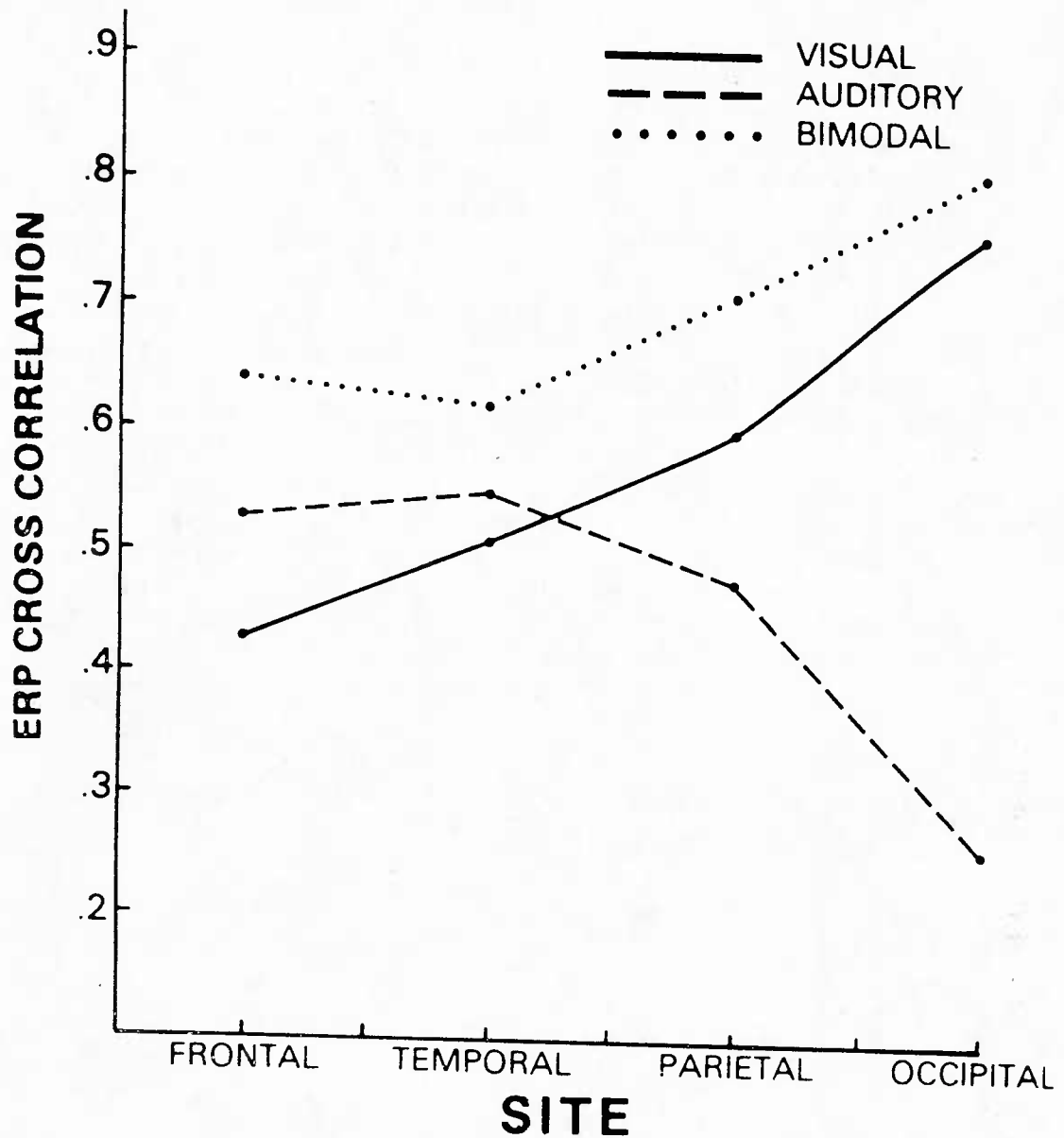


FIGURE 2 Stimulus-by-site interaction, mean values for modalities.

Mean correlations for the visual records increased nearly linearly from the frontal to the occipital sites. Auditory means were greatest at temporal and frontal sites, less at the parietal, and least at the occipital site.

Correlations between age and the stability measures for both groups ( $N=16$ ) appear in Table IV. The previous ANOVA showed no statistical differences between the two groups. Groups were combined to increase the range of ages of the subjects in order to assess age-stability relationships. Two statistically significant correlations were found at both occipital sites for visual records. Four of eight correlations (all negative) reached the  $p<0.05$  level of significant for auditory records. No significant relationships between age and bimodal stability measures were found.



# TEMPORAL STABILITY OF ERP RECORDS

TABLE IV  
Correlations of age with stability measures

Site	Stimulus		
	Visual	Auditory	Bimodal
F3	-0.06	0.47	-0.27
T3	0.23	-0.55 <sup>a</sup>	-0.09
P3	0.00	-0.34	-0.34
O1	0.52 <sup>a</sup>	-0.23	0.28
F4	0.21	0.46	-0.09
T4	0.22	-0.60 <sup>b</sup>	-0.08
P4	0.12	-0.52 <sup>a</sup>	-0.18
O2	0.56 <sup>b</sup>	-0.55 <sup>a</sup>	0.28

$df = 15$

<sup>a</sup> $p < 0.05$

<sup>b</sup> $p < 0.02$

## DISCUSSION

The potential value of using ERP measures in personnel assessment requires meeting specific criteria. These include sensitivity to individual differences and waveform stability during baseline conditions. To have value in predicting on-job performance, the measures would ideally be capable of monitoring real-time brain processing under simulated job conditions.

One of the main objectives of the current research was to determine what effects age and time between recording sessions have on the stability of ERP measures. These effects were assessed by comparing the two groups (A and B) for each ERP amplitude variable. In addition, stability measures between the groups were also assessed by analysis of variance. No statistically significant differences were found using either the *t*-test of amplitude measures or analysis of variance of stability measures.

Even though no statistically significant differences were found between the two groups for either *t*-test of amplitudes or ANOVA of stability measures, significant correlations were found between both occipital sites and age for visual records. Temporal stability did not relate to age for the other sites with visual stimuli. Kooi and Bagchi (1964) did not appear to determine the correlation between age and temporal stability of the waveform. They did, however, find correlations between age and their occipito-parietal amplitudes ( $r = 0.21$ ,  $p < 0.05$ ,  $N = 100$ ), but not for their vertex wave. Both the current research and that of Kooi and Bagchi dealt with adult subjects; however, the age range and mean age were considerably greater for the Kooi and Bagchi subjects than for the current research.

The Kooi and Bagchi study examined stability of amplitude and latency measures of specific components in the VEP. They mentioned the difficulty of measuring certain components in each of their subjects. Early in our current research (Lewis & Froning, 1981), we also found large individual differences in subject waveforms. Traditional peak detection procedures were not feasible. Instead, an integrated amplitude measure was required to assure obtaining at least one number for each subject's waveform. The metric was the microvolt root mean square. Similarly, the measure used to assess stability was the point-by-point cross-correlation, using all 256 time points along the waveform. This approach provided an objective measure of stability, not depending on identification of specific components. Such approach is reasonable when assessing

general characteristics of personnel. The approach addresses general amplitude, not latency, which is related to particular processing of specific brain events. Despite differences in measurement, both studies showed similar results, a positive relationship between age and stability and amplitude measures.

Kooi and Bagchi determined test-retest similarity for the wave III amplitude (ca 90–100 msec) in the occipital region ( $r=0.97$ ). They found however, the  $t$ -test between the two waveforms was not statistically significant, a finding also noted in the current research. Wave V (ca 140–160 msec) in the central region had a test-retest correlation of 0.87. Table I shows greater stability in Group B than in Group A. Age may have been a contributing factor to the somewhat increased stability found in Group B. Another contributing factor was the possibility of fatigue in Group A. Data were obtained from Group A in separate sessions during a 2–3 hour period of time. These subjects often come into the laboratory after performing duties for several hours. Each subject is given a questionnaire prior to testing to determine how tired he might feel. The subjects often reported being rested when in fact they were not. Multiple sessions during one day may have also contributed to subject fatigue. Fatigue was minimized in Group B by recording over several weeks and months.

Long-term stability of the VEP was examined by Dustman and Beck (1963). Twenty-five measurements, equally spaced over the first 300 msec of the waveform, were used to determine test-retest correlations (Pearson product-moment) over periods of several weeks. They found a median correlation of 0.88 for the intraindividual EPs (range from 0.72 to 0.99 from their seven subjects). Interindividual median correlation was 0.37 (range –0.29 to 0.92). Their data suggested high VEP stability within each subject and large differences between subjects, which were unique. Data in Table I also show large differences in stability at specific sites for individual subjects in both groups. At the Group B occipital sites, the range was similar to that found by Dustman and Beck (1963). Exceptions were subjects number 17 and 20. Much greater range of stability measures was seen at the occipital sites for Group A subjects.

In their 1965 paper, Dustman and Beck examined reliability and similarity in three groups of children: identical twins (IT), nonidentical twins (NIT) and matched, unrelated children (MC). They examined the first 250 msec in the VEP (occipital region) and found a mean correlation of 0.82 between pairs in the IT group, 0.58 between the NIT groups and 0.61 for the unrelated MC group. Correlations for the three groups were slightly lower from centrally recorded VEPs (0.74, 0.48, and 0.53 respectively). The authors suggest that there may be considerable subject differences in the VEP stability, with some individuals being very stable and others having a large amount of variability from day to day. Similarly, differences in waveform stability varying over time, site and individual may be seen in Table I.

Auditory EP (AEP) stability was examined by Buchsbaum, Henkin and Christiansen (1974). Using the product-moment correlation as an index of similarity, they found decreased AEP stability as age increased for their male ( $N=79$ ) and female ( $N=87$ ) subjects. Greatest stability occurred for the 6–9 year age group and least for the 40–60 year age group in the 200–300 msec period of the waveform. Table IV shows results similar to Buchsbaum, *et al.* Three of four right hemisphere sites showed statistically significant negative correlation between age and stability, with T4 showing the greatest negative correlation. The T3 site was the only left hemisphere site to be statistically significant. Neither frontal site significantly related age and stability; however, they did suggest a positive relationship.

AEP records were obtained from newborns by Ellingson, Danahy, Nelson, and Lathrop (1974). They found high reliability from day 1 to day 2 (mean  $r=0.84$ )

within and between sessions, and suggested that the AEP may be used to characterize an individual and determine intrasubject and intersubject changes. They also noted that the AEP gave higher stability than they found on a separate newborn sample using the visual EP (mean  $r=0.64$ ).

Data from Table II conflicts with the results of Ellingson *et al.* (1974). Stability measures in Table II are much less than seen for the visual records in Table I. Samples for the current research (adults) differed from that in the Ellingson *et al.* (1974) study (newborns). Greatest mean values for stability were found at the T3 and T4 sites for Group A, but at the frontal sites for Group B. Full development of the visual system is delayed longer than that for the auditory system and may account for the disparity in results between the current research and that for Ellingson *et al.* (1974). Buchsbaum and Coppola (1977) also found greater stability in their visual than in their auditory records, which agrees with the current findings. They also found greater stability in their area-under-the curve measure (analogous to that used in the current study) than for their baseline to-peak measure.

Nearly twice the number of stability measures were found for the visual records ( $N=60$ , Table I) than for the auditory ( $N=35$ , Table II). An age-stability negative relationship, noted earlier for the auditory records and a positive correlation for the visual records may have partially accounted for the difference between the visual and auditory stability.

Bimodal presentation provided higher relationships for the temporal stability measure (Table III,  $N=85$ , 66%) than for either the visual (Table I,  $N=60$ , 47%) or the auditory (Table II,  $N=35$ , 27%). In addition, no relationship was found between age and the bimodal stability measure (Table IV), unlike the visual and auditory measures. Much higher temporal stability relationships were found over the entire head (all sites) for the bimodal than for either visual or auditory records. This finding suggests a high within subject stability for the bimodal records. These records also showed a large amount of difference in individual subject patterns as may be seen in Figure 3.

The parietal and occipital regions in the top records display two distinct positive peaks in the 100 and 200 msec regions. Only a single peak is seen at the occipital sites in the lower records. The P4 site showed a similar morphology in both the upper and lower records. Other morphology differences may be seen between upper and lower records in the frontal and temporal regions also.

Sensory interaction and integration of the visual and auditory modalities appears essential for adequate performance of complex tasks such as reading (Lewis & Froning, 1981; Shipley, 1980). Bimodal records often produce greater amplitude and shorter latency of ERP components than visual or auditory records alone, suggesting sensory integration. Integration of the two sensory systems is probably the main contributor to increased stability of bimodal records compared to visual or auditory records alone. Data presented in this paper suggest that bimodal presentation may activate greater populations of brain fibers, a quantitative factor contributing to waveform stability.

From these data, it appears that large individual subject differences exist. ERP waveforms are highly stable within subjects from session to session, whether hours or months apart. Greatest stability was observed for bimodal presentation, less for visual and least for auditory records. Neither recording region (hemisphere) nor site location showed statistically significant differences across sessions. Differences in patterns of waveform stability existed for site and modality conditions across individuals. Greatest stability was found for bimodal presentation suggesting greater



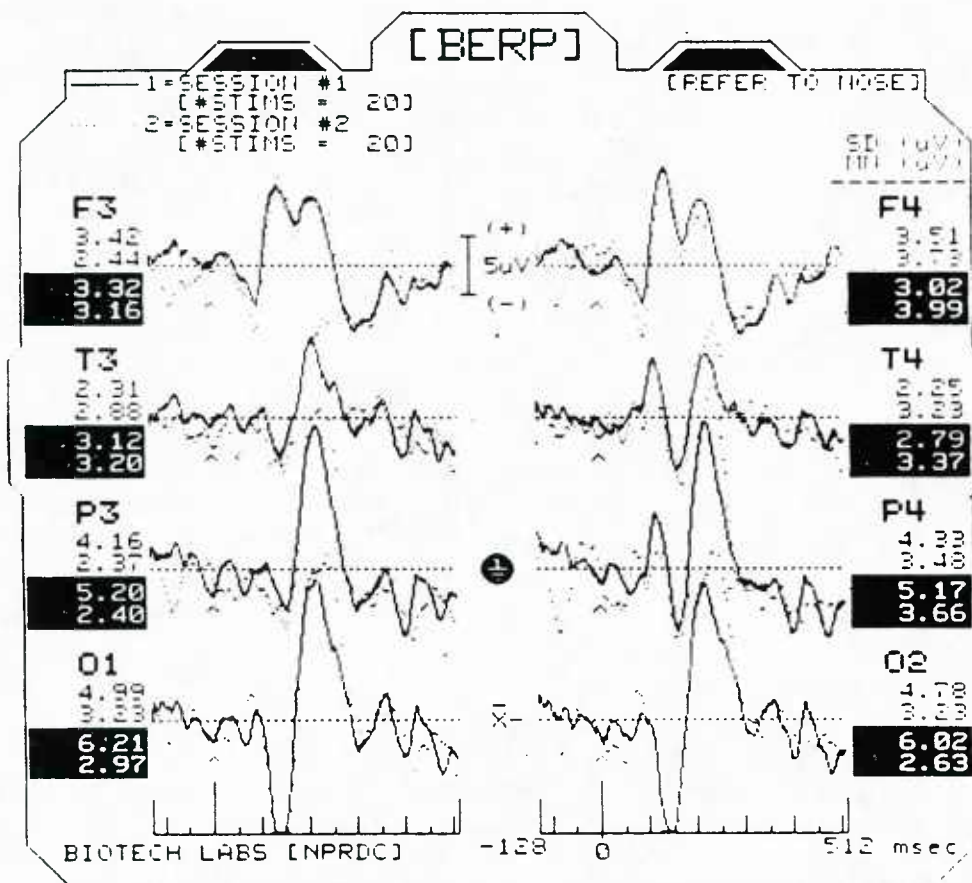
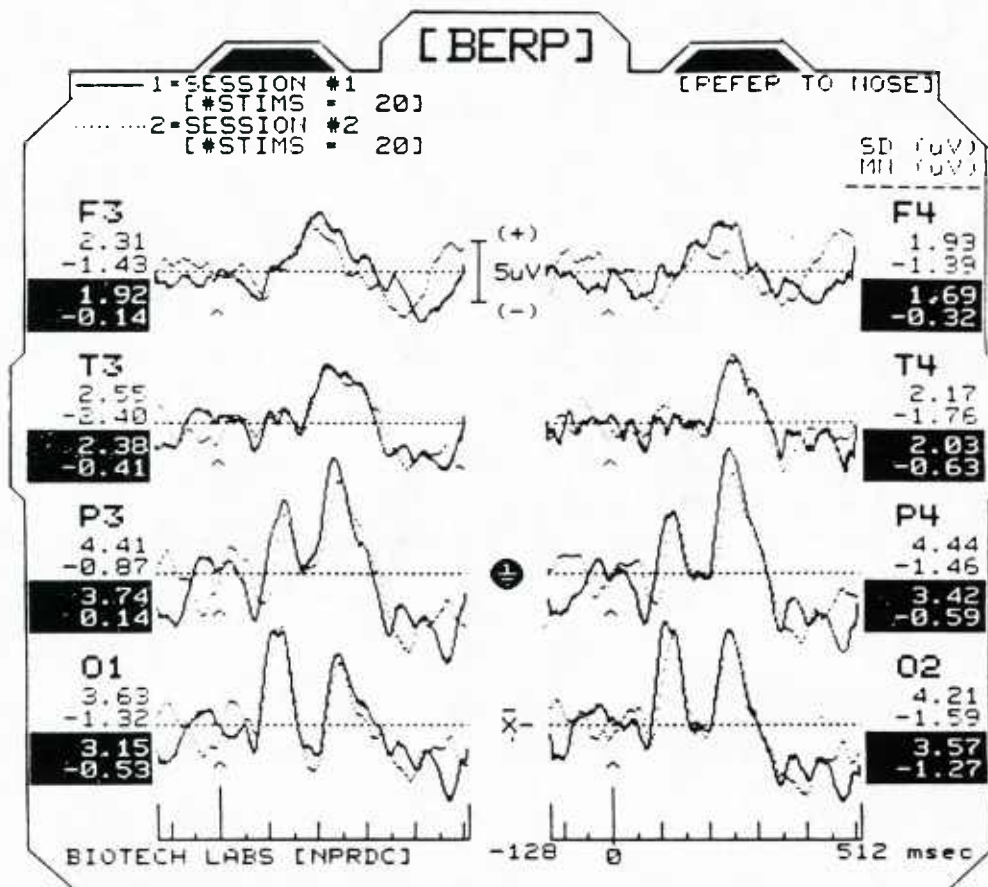


FIGURE 3 Sample bimodal ERP data from two subjects, showing individual differences in waveform shape. Top records are from subject No. 13, bottom records from subject No. 22.

brain tissue activation than that found for either visual or auditory presentation alone. Quantitative factors and possible resulting increased organizational integration factors may be operating to provide greatest stability under bimodal presentation, a condition not correlated with age.

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