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Journal

The International journal of neuroscience, 29(1-2)

ISSN

0020-7454

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Publication Date

1986-03-01

DOI

10.3109/00207458608985633

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PARAMETERS OF THE EVENT-RELATED POTENTIAL ARE RELATED TO FUNCTIONING IN THE MENTALLY RETARDED

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(Received June 25, 1985)

Event-related potentials were measured in 39 institutionalized profoundly and severely retarded clients divided into two groups: (1) clients assigned to sheltered workshop (WS); and (2) clients, residentially matched, but not assigned to workshop (NWS). Since the groups differed in intelligence ($p < 0.01$) the ERP was evaluated by analysis of covariance with IQ as the covariate. The WS group had significantly shorter latency of components reflecting initial registration (P1) and channeling (N1) of sensory input and significantly greater amplitude of indices of enhanced perception (P2) and cognitive elaboration (N2). The WS group had significantly more complex waves than the NWS group. A modest ($r = 0.31$, $p < 0.05$) relationship between P2 and IQ was observed. Multiple correlations of composite measures of the ERP with IQ were not significant but higher in the NWS than WS group. The possibilities that the ERP be used as a supplemental metric for functional evaluation or that the workshop experience might stimulate central nervous system plasticity were discussed.

Since the provocative report of Ertl and Schafer (1969) that intellectual ability was coded in the event-related electrical activity of the brain, many studies with mixed results have followed. One reason for inconsistent findings is that many different parameters of the event-related potential (ERP) have been related to many different tests of intelligence. Component latency (Ertl & Schafer, 1969; Perry, McCorry, Cunningham, Calgout & Street, 1976), component amplitude (Haier, Robinson, Braden & Williams, 1983; Shagass, Roemer, Strassmour & Hasiasen, 1981), waveform variability (Callaway & Halliday, 1973), habituation (Schafer & Peeke, 1982), waveform complexity (Hendrickson & Hendrickson, 1980) and hemispheric asymmetry (Rhodes, Dustman & Beck, 1969; Richlin, Weisinger, Weinstein, Giannini & Morgens-tern, 1973) all have been compared with measures of intelligence. In general, although there are studies with negative results, higher intelligence has been related to: (1) shorter component latencies; (2) increased component amplitude; (3) faster habituation; (4) greater waveform complexity; (5) decreased variability; and (6) greater hemispheric asymmetry.

An electrophysiological index of intelligence has enormous practical promise. The psychometric measurement of intelligence in severely and profoundly retarded persons can be unreliable due to factors which may not reflect intellectual potential (e.g., command compliance). Thus, selection of a test of intelligence is important and, as abstracted from the literature, includes a wide range of possibilities (whole or abbreviated versions of the Stanford-Binet, Wechsler Tests, Peabody Picture Vocabulary Test, or Ravens Progressive Matrices). Hence, a valid procedure with minor de-

The support of Dr. Francis Crinella is gratefully acknowledged. The technical assistance of Robert Isenhardt and Alson Wong is appreciated. Address correspondence to: Curt A. Sandman, Ph.D., Fairview Developmental Community, 2501 Harbor Boulevard, Costa Mesa, CA 92626.

mands for patient compliance is of great interest. Several studies (Shucard, 1973; Jensen, Schafer & Crinella, 1981) supplemented measures of intelligence with tests of function or ability and, subsequently enhanced the observed relationship with the ERP. In order to examine further this possibility the current study was designed to investigate a number of components of the auditory ERP, psychometrically measured intelligence and level behavioral functioning.

METHOD

Subjects

Thirty-nine mentally retarded clients from the Adolescent Habilitation programs at Fairview Developmental Community, an institution for retarded individuals in Costa Mesa, CA, were chosen randomly to participate in the study. The clients comprised two groups: (a) clients who worked in a structured workshop (WS); ($N=22$); and (b) clients who were matched with the WS group in terms of residential placement (theoretically reflecting habitability) but not assigned to a workshop (NWS) ($N=17$).

Test of Intelligence

The Peabody Picture Vocabulary Test (PPVT) of intelligence (Dunn, 1965) is a single receptive word test consisting of 150 plates, each containing 4 pictures. The subject is read a word and asked to point to the picture which describes the word. Reliability estimates in adult retarded clients range from 0.61 (Dunn & Brooks, 1960) to 0.87 (Burdoff & Purseglove, 1963). Measures of construct validity span a broader range: from 0.41–0.43 (Kimball, 1960; Burnett, 1965) to 0.82–0.88 (Burdoff & Purseglove, 1963; Moss, 1962).

Event-Related Potential

Subjects reclined in a comfortable chair while transducers were applied for recording EEG from each hemisphere of the brain. Grass cup AgAgCl electrodes were attached to the scalp above the right and left hemispheres of the brain according to the International 10–20 system. Monopolar placements at C3 and C4 were referenced to linked mastoids. The electrode sites were swabbed with acetone and the electrodes filled with Grass EEG cream and affixed to the scalp with Collodion. Pairs of electrodes with impedance of greater than 10,000 ohms were replaced. Electrodes with differences between the left and right hemispheres of greater than 1,000 ohms were corrected. The EEG signal was amplified by Grass ac preamplifiers with the low frequency filter set at 1 Hz and the high frequency filter set at 35 Hz. The subjects were fitted with headphones (Senheisser HD 400), for pure tone (600 Hz) auditory stimulation.

Apparatus. Physiological recordings were obtained with Grass, Model 7P5 amplifiers. On-line averaging of the ERP with an Apple II microprocessor equipped with a Mountain Hardware A-D card provided a refreshed, running average as well as the EEG sample from which the average was computed. The microprocessor rejected all samples with amplitudes over 100 μV . The ERP was analyzed by sampling the

EEG at 1 KHz for 640 ms. A 500 ms sampling period was zeroed by averaging a 140 ms prestimulus epoch.

Method of Data Analysis

Peak Identification. Prominent positive and negative peaks were identified by an experimenter unaware of group membership and scored with an automated procedure. The peaks of interest included: the first positive peak (P1, between 50–120 ms), the first negative peak (N1, 90–160 ms); the second positive peak (P2, 140–240 ms); the second negative peak (N2, 200–350 ms); and the third positive peak (P3; 280–450 ms). For each client the absolute amplitude (peak-to-peak values) and latency of each peak were recorded.

Waveform Complexity. Since complexity of the ERP may reflect cognitive complexity, e.g., higher intelligence, (Hendrickson & Hendrickson, 1980), a modified string measure was calculated. The absolute values of the successive peaks were summed and divided by the latency of the last term ($P1 + N1 + P2 + N2/N2$ and $P1 + N1 + P2/P2$).

RESULTS

Even though the clients were not placed into WS and NWS groups based upon measures of intelligence, analysis of variance indicated that they differed in intelligence. The WS group scored significantly higher on the PPVT, than the NWS group ($F=11.42$, $df=1/37$, $p<0.01$). As is apparent in Table I, the WS group was older than the NWS group, but the difference was not statistically significant ($F=3.72$, $df=1/37$, $p>0.05$).

The amplitude, latency and complexity of the ERP for the WS and NWS group and for each hemisphere of the brain were analyzed with a 2×2 analysis of variance and then with analysis of covariance (using age and IQ as covariates). The amplitude for both P2 ($F=22.78$, $p<0.0001$) and N2 ($F=6.14$, $df=1/37$, $p<0.02$) were significantly larger for the WS group (Table I). Comparison of the latencies revealed that P1 ($F=5.90$, $df=1/37$, $p<0.03$) and N1 ($F=4.44$, $df=1/37$, $p<0.04$) were shorter (the responses occurred earlier) for the WS group (Table I). None of the contrasts for hemisphere reached acceptable levels of statistical significance. Further, none of the interactions was statistically significant.

Since the groups differed significantly in intelligence and were of different ages, analysis of covariance was computed with age and intelligence used separately, as covariates. None of the findings changed as a function of partialling IQ from the variable arrays. The latency of P1 ($F=4.06$, $df=1/36$, $p<0.05$, beta estimate 0.06) and N1 ($F=4.89$, $df=1/36$, $p<0.03$, beta estimates 0.45) remained statistically significant. The amplitude of P2 ($F=20.11$, $df=1/36$, $p<0.0001$, beta estimates -0.05) and N2 ($F=7.81$, $df=1/36$, $p<0.008$, beta estimates -0.09) also were unchanged with IQ as a covariate. Similarly, age as a covariate had no detectable influence on the latency of P1, N1 or the amplitudes of P2 or N2.

The measures of complexity (modified string measure) were subjected to analysis of variance. The measures terminating at P2 ($F=10.15$, $df=1/37$, $p<0.003$) and N2 ($F=9.22$, $df=1/37$, $p<0.004$) were highly significant. In both cases the complexity

TABLE I

Means and standard deviation of age, IQ and components of the event-related potentials of the brain in workshop (WS) and no workshop (NWS) clients

	Low functioning (N=17)		High functioning (N=22)	
Age	22.7±2.8		28.4± 6.7	
IQ	16.6±5.7		32.8±15.9 ^b	
Event related potentials	Hemispheres			
	Left	Right	Left	Right
Amplitude				
P1	2.8±2.5	2.5±2.5	2.3±1.6	2.3±1.6
N1	7.4±4.7	6.9±4.9	8.3±4.8	8.1±4.3
P2	3.8±4.4	4.0±4.1	13.0±7.3 ^b	13.0±6.5 ^b
N2	7.4±6.6	7.4±6.2	12.1±5.9 ^a	12.4±5.8 ^a
P2	7.0±7.3	6.3±6	7.4±3.8	7.8±3.9
Latency				
P1	85± 44	83± 46	55± 26 ^a	59±30 ^a
N1	140± 56	139± 56	106± 30 ^a	109±40 ^a
P2	222± 62	224± 60	196± 55	196±50
N2	308± 72	309± 7	311± 74	316±69
P3	334±175	334±176	402±101	406±99

^a*p* < 0.05 (HF vs. LF).

^b*p* < 0.01 (HF vs. LF).

(amount of information or total amplitude divided by the time of the epoch) was greater for the WS group. As with the measures of latency and amplitude, covariance with intelligence and age was inconsequential in the significance between groups.

The variables were analyzed further with bivariate correlational analysis. In Table II, the matrix of variables of interest for all subjects and for the WS and NWS subjects analyzed separately, are presented. Only the amplitude of P2 was significantly related to IQ. The positive relationships of age with IQ, with the amplitude of P2 and N2 and with measures of complexity were significant. Since the ANOVAS indicated that the latency measures of early components and amplitude measures of later components were related to level of functioning, the correlation was computed among these measures. Significant, negative relationships were detected for all of the latency values of P1 and N1 with the amplitudes of P2 and N2 and the measures of complexity.

The separate correlations computed for the WS group are partially consistent with the overall analysis. The correlation of age with the amplitude of the ERP was of the same pattern as seen with all the subjects except that the relationship between the latency of P1 and amplitude of P2 was significant. In the NWS group, only the relationship between amplitude of P3 and latency of N1 was statistically significant. However, there was an interesting trend (*r* = 0.33) suggesting that depressed amplitude of P1 was related to lowered intelligence.

Although the subject *x* variable ratio was less than 2:1, the correlational matrix for all of the subjects was submitted to principal component analysis and a varimax rotation. The results of the varimax rotation are summarized in Table III. Of interest

TABLE II
Correlational relationships among amplitude measures of the
ERP and Age, IQ and latency of P1 and N1

	Age	IQ	Lat P1	Lat N1
All clients ($N=39$)				
Amp P1	0.04	0.18	-0.02	-0.01
Amp N1	0.39 ^a	0.05	-0.25	-0.11
Amp P2	0.59 ^b	0.31 ^a	-0.48 ^b	-0.41 ^b
Amp N2	0.41 ^b	0.14	-0.36 ^a	-0.45 ^b
Amp P3	0.21	0.19	-0.05	-0.18
Complexity P2	0.47 ^b	0.19	-0.46 ^b	-0.42 ^b
Complexity N2	0.44 ^b	0.19	-0.50 ^b	-0.47 ^b
Workshop group ($N=22$)				
Amp P1	0.06	0.29	-0.01	0.24
Amp N1	0.57 ^b	0.07	-0.20	0.07
Amp P2	0.50 ^a	-0.01	-0.46 ^a	-0.34
Amp N2	0.43 ^a	-0.07	-0.26	-0.37
Amp P3	0.39	-0.09	0.43 ^a	0.32
Complexity P2	0.43 ^a	0.01	-0.40	-0.26
Complexity N2	0.35	-0.05	-0.42 ^a	-0.35
Non workshop group ($N=17$)				
Amp P1	0.34	-0.33	-0.07	-0.21
Amp N1	-0.07	-0.18	-0.30	-0.17
Amp P2	0.09	-0.16	-0.30	-0.27
Amp N2	0.11	-0.02	-0.31	-0.40
Amp P3	0.17	0.14	-0.43	-0.52 ^a
Complexity P2	0.18	-0.20	-0.37	-0.45
Complexity N2	0.14	-0.14	-0.43	-0.45

^a $p < 0.05$.

^b $p < 0.01$.

are the loadings on the first factor of age and IQ with amplitudes of N1, P2, N2 and the measures of complexity. The second factor comprises latencies of the major components up to N2. The third factor is an amplitude factor of the early components P1 and N1. The coherence of the factors falls off after these three factors. These results should be considered heuristic and indicate that cumulative measures of the ERP, rather than single values, may have greater predictive utility with regard to assessment of cognitive capacity.

Since results of the factor analysis suggested that a composite of the ERP measures (Perry *et al.*, 1976) may relate to IQ, a multiple regression was computed. The measures from C3 and C4 were highly related, thus, only the C3 variables were included. The squared multiple correlation (SMC) for IQ with the ERP was not significant ($R=0.23$, $F=0.80$, $df=27/10$, $p>0.05$). Separate analyses for the WS ($R=0.19$, $F=0.23$, $df=10/10$, $p>0.05$) and NWS group ($R=0.78$, $F=2.14$, $df=10/6$, $p>0.05$) also failed to reach significance. The SMC for the NWS group clearly was higher than that for the WS group and supports earlier results.

TABLE III
Varimax rotation of PCA for age, IQ and the ERP

		Factor 1	Factor 2	Factor 3
Age	3	0.708		
IQ	6	0.370		
C3P1AMP	9			0.896
C4P1AMP	10			0.881
C3P1LAT	11		0.789	
C4P1LAT	12		0.817	
C3N1AMP	13	0.646		0.654
C4N1AMP	14	0.648		0.640
C3N1LAT	15		0.870	
C4N1LAT	16		0.892	
C3P2AMP	17	0.942		
C4P2AMP	18	0.929		
C3P2LAT	19		0.856	
C4P2LAT	20		0.860	
C3N2AMP	21	0.697		
C4N2AMP	22	0.697		
C3N2LAT	23		0.678	
C4N2LAT	24		0.706	
C3P3AMP	25			
C4P3AMP	26			
C3P3LAT	27			
C4P3LAT	28			
Complexity C3/N2		0.810	-0.384	
Complexity C4/N2		0.798	-0.374	0.354
Complexity C3/P2		0.817		0.432
Complexity C4/P2		0.818		0.429
VP		7.299	5.994	3.309

The VP for each factor is the sum of the squares of the elements of the column of the factor pattern matrix corresponding to that factor. When the rotation is orthogonal, the VP is the variance explained by the factor.

DISCUSSION

The robust relationship between level of functioning and event-related activity of the brain, independent of intelligence, was the most remarkable result of the present study. These findings suggest new possibilities for describing the elusive relationship between information coded in the electrical activity of the brain and human potential. An index of positive, adaptive functioning (placement in a workshop) in severely and profoundly retarded clients was related to components of the ERP. These data are reminiscent of the Shucard and Harris (1973) report of the enhanced relationship between amplitude and latency of the ERP, and adaptive measures of intelligence or skill. As such, these findings may serve as a caution for attempts to demonstrate relationships between brain functioning and psychometric measures of intelligence in the retarded. Further, since measures of intelligence in the retarded may be invalidated by such factors as command compliance, supplementary indices not requiring compliance should be included.

Interestingly, the variables contributing to the relationship between the ERP and level of functioning in the retarded were similar to the variables often cited as related to intelligence. Shorter latency (Shucard & Harris, 1973; Chalke & Ertl, 1965; Nodar &

Graham, 1968), and increased amplitude (Lelord, Laffont & Jusseaume, 1976; Haier *et al.*, 1983) of the ERP often has been reported to be related to increased intelligence. In the current study, the latency of early components (P1 and N1) and the amplitude of later components (P2 and N2) were related independently to level of functioning. Thus, the speed of initial stimulus registration (P1) and channeling of the sensory input (N1), coupled with indices of enhanced perception (P2) and cognitive elaboration (N2), cooperated in defining the WS group. In agreement with Haier *et al.* (1983), virtually nothing was added to this analysis by the measure of waveform complexity.

Even though the correlation between IQ and amplitude of P2 was modest ($r=0.31$) it was consistent with the direction Haier *et al.*, (1983; Lelord *et al.*, 1976) and magnitude (Jensen *et al.*, 1981) reported previously in normal and retarded subjects. The finding of Perry *et al.*, (1976) that composite measures of the ERP only related significantly with performance and not verbal measures of intelligence, may account for the weak relationship with the PPVT but the strong association with level of function.

The multivariate analysis yielded inconclusive results. The rotated factor structure suggested relationships among amplitude measures of the ERP, age and intelligence. This heuristic analysis supported the composite ERP approach of Perry *et al.*, (1976) and the unique, neural adaptability index, proposed by Schafer (1982) and Jensen *et al.*, (1981). These studies, coupled with the current report, indicate that latency and amplitude of the ERP share communality with psychometric intelligence. However, the multiple correlational analysis indicated nonsignificant relationships between a "composite" ERP and a verbal measure of intelligence. Clearly, any relationship is weak, and the behavioral measurement (level of functioning) provided the best index of capacity. As such, the present study provides preliminary support for the use of tests such as the ERP to assess level of function in mentally retarded individuals. Further studies are required to validate the ERP as a predictor of adaptability (Schafer, 1982). Since compliance in our simple paradigm is not necessary, the ERP may be a promising assessment tool.

An alternative hypothesis to the possibility that ERPs reflect functions is that the workshop experience altered the ERPs of the brain. There is sufficient support for experience altering the brain of the immature nervous system (see Rosenzweig, 1983 for a review). Recently we (Sandman & Donnelly, 1983) have reported that elderly subjects, who had been active in a volunteer program, exhibited less age-related decline in the ERP than age-matched subjects just entering the program. The implication pertinent to the present study may be that even the mature nervous system retains a degree of plasticity. Certainly, this possibility can be evaluated by examining changes in the ERP, longitudinally, beginning when workshop placement is initiated.

Finally, the relationship between the ERP and age deserves mention. Typically, with advancing age, extended latency of ERP components is observed. (Ford, Duncan-Johnson, Pfefferbaum & Kopell, 1982; Ford, Pfefferbaum, Tinklenberg & Kopell, 1982; Brown, Marsh & LaRue, 1983). This was not found in the present study. Instead, latency was unaffected and amplitude increased with age. The age range of the clients (18–52 years) may have been too restricted (especially at the older ages) to reflect typical aging trends. Alternatively, the process of aging among the retarded may follow atypical patterns. This possibility requires further study.

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