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P3 and Stimulus Incentive Value

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ABSTRACT

Event-related potentials were recorded to two equiprobable, task-relevant visual stimuli (0.00 and 1.00) under three different conditions. In the baseline condition subjects attended to both stimuli and pressed the appropriate button to each stimulus. In the Accuracy/Incentive condition subjects earned one dollar each time the 1.00 stimulus was presented by accurately pressing the appropriate button after each stimulus. Incorrect presses to either stimulus resulted in the loss of a dollar. In the Speed-Accuracy/Incentive run, subjects could only earn one dollar to the 1.00 stimulus if they accurately pressed the correct button within 350 msec. Reaction times greater than 350 msec to either stimulus resulted in the loss of a dollar. The results indicate that the amplitude of the P3 component is significantly different to equiprobable task-relevant stimuli with differential incentive values. P3 may reflect the subjective motivational properties of stimuli.

DESCRIPTORS: Event-related potentials, P3, Incentive value, Stimulus significance, Motivational properties.

In 1965, Sutton and his colleagues first reported the now classical observation that a late positive component (P3) of the event-related potential (ERP) occurring between 300–600 msec post-stimulus indexed the amount of stimulus uncertainty (Sutton, Braren, Zubin, & John, 1965). More recently, a number of investigators have reported that the ERP may contain several late positive components (N. Squires, K. Squires, & Hillyard, 1975; Ford, Roth, & Kopell, 1976; K. Squires, Donchin, Herning, & McCarthy, 1977; Friedman, Vaughan, & Erlenmeyer-Kimling, 1978, 1981) which can be elicited under different experimental conditions, and may have different topographical distributions and times of occurrence. While a complex of late positive components has been studied, most investigators have selected to examine the P3 component originally identified by Sutton and his co-workers (1965).

Since the initial report, a vast number of investigators have attempted to examine the functional significance of this endogenous brain event (for reviews see Donchin, Ritter, & McCallum, 1978; Hillyard, Picton, & Regan, 1978; Tueting, 1978; Donchin, 1979; Sutton, 1979). At present there is no single unifying concept which satisfactorily explains the functional significance of the P3 component. Indeed a variety of psychological factors have been suggested to explain the functional significance of P3, including resolution of uncertainty, stimulus evaluation, orienting response, equivocation, subjective probability, and decision confidence (Donchin, 1981). Experimental studies indicate that each of these factors influence P3 amplitude when all other factors are held constant. For example, the amplitude of P3 is directly related to the degree of *a priori* improbability (Tueting, Sutton, & Zubin, 1970; Duncan-Johnson & Donchin, 1977), and a large P3 can even be elicited in the absence of an expected stimulus (Pritchard, 1981).

Sutton, Tueting, and Hammer (1978) suggested the concept of "value" or "importance" in interpreting the P3 component. They proposed that rare or unexpected events may be inherently more important than commonly occurring situations. Furthermore, they suggested that by definition, target

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stimuli are given greater importance than non-target stimuli. These investigators reported that P3 was found to be larger the greater the value of the subject's bet. A similar relationship between P3 amplitude and the value of the subject's bet was also reported by Johnston (1979). More recently, Homberg, Grünewald, and Grünewald-Zuberbier (1981) reported that the P3 amplitude is significantly larger in a high payoff condition than in low or no payoff conditions.

While the P3 component of the event-related potential indexes cognitive processes, its functional significance may best reflect the subjective value of a stimulus to a subject. It may be postulated that the process manifested by P3 is only initiated whenever the organism is presented with motivationally significant stimuli.

The present experiment was designed to investigate the effects of stimuli with high and low incentive value on the P3 component, in a paradigm where all stimuli are task-relevant and their occurrences are equiprobable.

Methods

Subjects

The subjects were 24 young adults (20 males and 4 females), with a mean age of 25.8. They were screened for medical problems and were paid for participating in the experiment. None had participated in previous experiments and all were naive as to the goals of the present study.

Stimuli

Two visual number stimuli were used throughout the course of the experiment (0.00, 1.00). Each stimulus was generated by a computer (PDP 11/40) and displayed on a computer CRT one at a time. The visual stimuli subtended a visual angle of 3.8 degrees and were displayed in the center of the screen for 20 msec. The two stimuli were presented randomly for a total of 30 times each with a random interstimulus interval of 2–5 sec. A dimly illuminated point in the center of the CRT served as a fixation point.

Procedure

Subjects were seated comfortably in a dimly lit sound-attenuated chamber with their heads resting on a chin rest; they were carefully instructed to fixate on the fixation point. In the baseline condition (Run 1), subjects were instructed to look at each visual stimulus and to press button B after each presentation of the stimulus 0.00, and button A after each presentation of stimulus 1.00. The experimenter stressed the importance of error-free performance without ever mentioning speed of response.

In the Accuracy/Incentive condition (Run 2), subjects were told that each time stimulus 1.00 was presented it signified one dollar which could be earned by correctly pressing button B after the 1.00 stimulus. They were instructed to press button A after the 0.00 stimulus; however the presentation of the 0.00 stimulus signified no money. The subjects were told that each button pressing error would result in one dollar being subtracted from the total earnings. A total of 2 sec was allotted for each behavioral response. With error free performance, subjects could potentially earn a total of $30.00 in this run.

In the Speed-Accuracy/Incentive condition (Run 3), subjects again had the opportunity to earn money; however the conditions for earning money were changed. As in Run 2, the 1.00 stimulus signified $1.00 and 0.00 signified no money. However, in this run, the subjects were told to press as quickly as possible and as accurately as possible to both visual stimuli. In order to win one dollar in this run, the subject had to press the correct button after the 1.00 stimulus within 350 msec. They were told that reaction times in excess of 350 msec to either stimulus or incorrect button presses would automatically result in the loss of one dollar. Nevertheless, in this run as in run 2, optimal performance could potentially result in earnings of $30.00. The order of the three conditions was constant across all subjects.

Recording

ERPs were recorded with Grass gold electrodes from four midline (F_z, C_z, P_z, and O_z) and two lateral (P_3 and P_4) scalp locations according to the 10-20 International System. Eye-movement artifacts were monitored by recording the electro-oculogram (EOG) from two electrodes located above and below the right eye. Trials with excessive eye movements (50 μV) were automatically rejected and not included in the average. All recording leads were referenced to combined ears. A ground electrode was located on the forehead. Resistance of all scalp electrodes was kept below 3KΩ. The potentials were amplified 20,000 times (Grass model P511J) employing filters from .3 to 60 Hz. Stimulus presentation and data acquisition were controlled by a PDP 11/40 computer which sampled and digitized the individual trial data at 143 points/second. All single ERPs were simultaneously stored on disk and magnetic tape for subsequent analysis. The averaging epoch began 49 msec before the onset of the visual stimulus and continued for 700 msec subsequent to stimulus presentation. All artifact-free ERPs were averaged because the subjects did not make any errors in the tasks. In addition all ERPs obtained in Run 3 were averaged together regardless of the reaction time values. ERP averages were obtained for each condition separately (Runs, Stimuli, Electrodes). All reaction time data were recorded and stored in the computer.

Data Analysis

Averaged event-related potentials for 24 subjects across six electrodes and for all experimental conditions were subjected to a Principal Components Analysis (PCA) with varimax rotation using the covariance matrix (BDMP 4M). In total, 864 waveforms were entered in the PCA. The factor scores under the different experimental conditions (Run, Stimulus, Electrodes) were averaged. These factor scores (which are a measure of the contributions of each factor to the average waveforms) were analyzed using a three-way analysis of variance for each factor separately to determine the effects of Run × Stimulus × Electrodes.

Repeated measures analyses of variance (ANOVA) assume homogeneity of population variances and covariances. It is well known that violations of this assumption commonly result in an increased probability of Type I error (Winer, 1971). In order to correct for possible nonhomogeneity, we reduced the degrees of freedom for each test according to the method of Jennings and Wood (1976). This results in a more conservative test, $F(1/N-1)$. In our study the degrees of freedom were reduced to 1 and 23 when testing all main and interaction effects.

It has been demonstrated that time and voltage variations of the individual ERP waveform commonly occur with each stimulus presentation (McGillem & Aunon, 1977). In order to systematically account for and correct the time variations or latency jitter of the components of the single ERPs, we use the Latency Corrected Average (LCA) (McGillem & Aunon, 1977; Aunon & McGillem, 1979) and the more recent continuous LCA (McGillem, Aunon, & Pomalaza, Note 1). The Latency Correction is important in the present study because it has been shown that P300 latency and Reaction Time covary under certain conditions (Ritter, Simson, & Vaughan, 1972; Kutas, McCarthy, & Donchin, 1977).

In the LCA procedure the individual data segments of each ERP are first passed through a minimum mean square error filter designed to measure the noise (Aunon & McGillem, 1979). After preprocessing by this filter the waveforms are searched by the computer for peaks in each ERP. The components are then identified and grouped by combining into common groups those peaks which best fit a predetermined zero crossing criterion. The computer algorithm then returns to the original (unfiltered) waveform and determines such quantities as means and variances of amplitudes and latencies of peaks, shapes of latency corrected averages, etc...

The continuous LCA (McGillem et al., Note 1) was developed to yield a more conventional representation of the information contained in the LCA. In this procedure, the discontinuous sections of the LCA are fitted using a mean square error criterion with a series of sinusoids. For those sections of the LCA where no information is available (due to low signal-to-noise ratio) the conventional average is used to fit these specific regions. The LCA procedures were conducted on 18 randomly selected subjects. Subsequent to LCA, baseline to peak measurements were obtained for P3 as were latency measurements. These data were also subjected to a repeated measures analysis of variance as described above. In the data reported, the significance for all statistical tests exceeds the .05 level (two-tailed test).

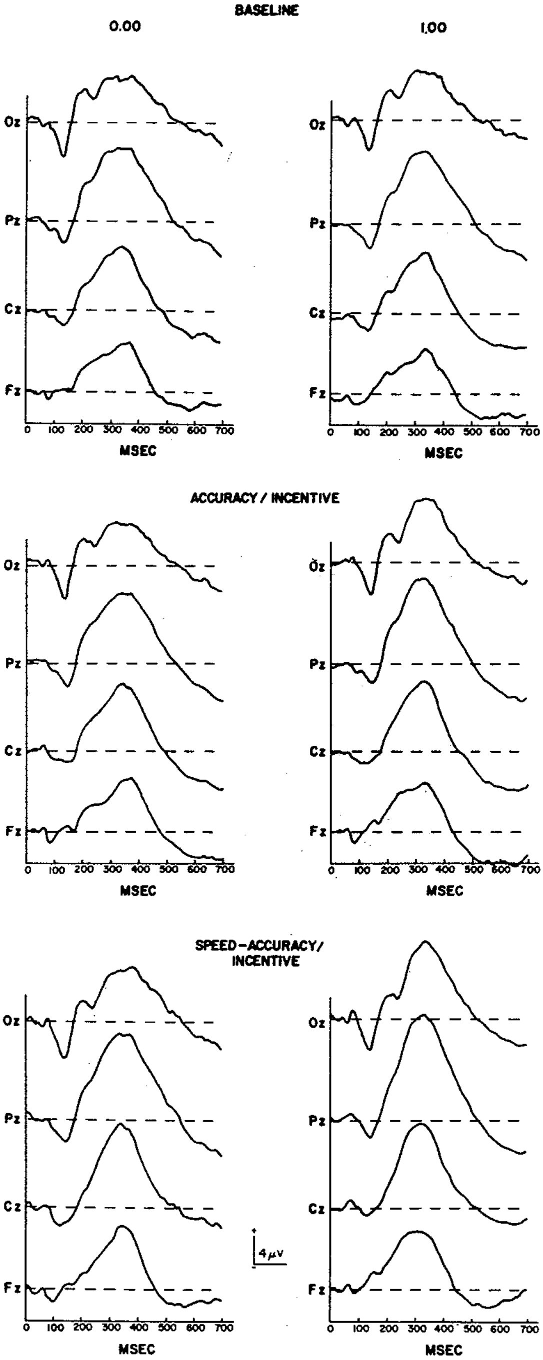

Figure 1. Grand mean ERP waveforms (positive up) to the 0.00 and 1.00 stimuli at each electrode site (F_z, C_z, P_z and O_z) under the three experimental conditions: baseline, accuracy/incentive, and speed-accuracy/incentive.

Results

The grand mean ERPs obtained to all stimuli in each condition are illustrated in Figure 1. Principal Components Analysis (PCA) was performed on the averaged pooled waveforms of the first 602 msec post-stimulus obtained from each individual subject, and the factor scores obtained for each derived component were used for subsequent statistical analyses. The rotated (varimax) loadings based on the covariance matrix appear in Figure 2.

The first four factors obtained from the PCA after varimax rotation account for 84.3% of the variance. Factor 1 is maximum at P_z and peaks at 329 msec; it corresponds to the P3 component. Factor 2 is maximum at P_z and represents a rather broad component, namely the slow wave (SW) peaking around 560 msec. Factor 3 peaks at 224 msec and may represent the P2 component. Factor 4 peaks at 140 msec and may reflect the N1 component. Each of the four factors was subjected to a three-way repeated measures analysis of variance (ANOVA). Degrees of freedom were reduced to 1 and N − 1 (1/23) according to the method outlined by Jennings and Wood (1976) to take into account unequal variance-covariance matrices in repeated measure designs. Only the ANOVA for Factor 1 yielded statistically significant ($p < .05$) main effects for stimuli and run. Table 1 summarizes the three way (Run × Stimulus × Electrodes) ANOVA for Factor 1. Mean Factor 1 scores obtained at P_z electrode 3 for each of the three experimental runs are presented in Figure 3. The *t* tests for simple effects performed on factor scores obtained for Stimulus and Run at the P_z electrode revealed the following. The P3 components obtained to stimulus 0.00 and stimulus 1.00 were not significantly different in Run 1 (Baseline). The P3 component elic-

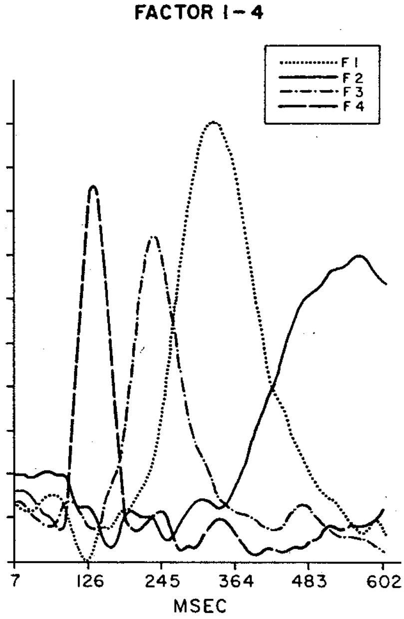

Figure 2. Factor loadings of first four factors obtained from Principal Components Analysis with varimax rotation.

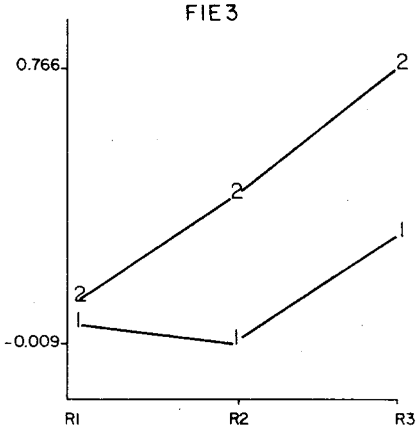

Figure 3. Mean Factor 1 (F1) scores obtained at P_z electrode 3 (F1E3) for each of the three experimental runs (R_1, R_2, R_3); 1 indicates stimulus 0.00; 2 indicates stimulus 1.00.

Table 1

Three way analysis of variance for Factor 1 mean scores (P329)

Source	Sum of Squares	*df*	Reduced *df*	Mean Square	*F*
Mean	0.00000	1		0.00000	
Error	572.80814	23		24.90470	0.00
Run	24.99217	2		12.49608	
Error	55.52085	46	1/23	1.20698	10.35**
Stimulus	12.32624	1		12.32624	
Error	19.62980	23	1/23	0.85347	14.44**
Run × Stimulus	3.05415	2		1.52708	
Error	17.17085	46	1/23	0.37328	4.09
Electrode	26.86261	5		5.37252	
Error	102.16796	115	1/23	0.88842	6.05*
Run × Electrode	0.92741	10		0.09274	
Error	10.09242	230	1/23	0.04388	2.11
Stimulus × Electrode	4.12922	5		0.82584	
Error	5.16926	115	1/23	0.04495	18.37**
Run × Stimulus × Electrode	1.76733	10		0.17673	
Error	6.38088	230	1/23	0.02774	6.37*

*$p<.05$
**$p<.01$.

Table 2

ANOVA for P3 amplitudes from latency corrected averages (P_z)

Source	Sum of Squares	*df*	Mean Square	*F*
Mean	1503.115	1	1503.115	163.37
Error	156.408	17	9.200	
Run	10.587	2	5.293	10.70**
Error	16.825	34	0.494	
Stimulus	4.650	1	4.650	20.90**
Error	3.782	17	0.222	
Run × Stimulus	3.851	2	1.925	5.76**
Error	11.367	34	0.334	

**$p<.01$.

ited by the 0.00 stimulus did not differ in amplitude between Runs 1 and 2 but increased significantly ($p < .05$) between Run 1 and Run 3 and between Run 2 and Run 3 ($p < .001$). This same component differed significantly across each of the three runs when elicited by stimulus 1.00 (Run 1 and Run 2, $p < .01$; Run 1 and Run 3, $p < .001$; Run 2 and Run 3, $p < .01$).

Subsequent to the latency corrected averaging procedures, the P3 amplitudes (P_z) for the two stimuli across the three experimental conditions were also subjected to an ANOVA. As indicated in Table 2, the results for Run and Stimulus were statistically significant as was the interaction of Run × Stimulus. The ANOVA for P3 latencies did not yield any statistically significant main effects.

Reaction times to the 1.00 stimulus ($\bar{X}=657.46$) did not differ from those to the 0.00 stimulus ($\bar{X}=656.81$) in Run 1 (Baseline), but in Run 2, the Accuracy/Incentive condition, the reaction times to 1.00 ($\bar{X}=615.10$) were significantly ($p < .01$) shorter than both the reaction times to 0.00 in the same run ($\bar{X}=653.47$) and those to both stimuli in Run 1. In Run 3, the Speed-Accuracy/Incentive condition, the reaction times to the 1.00 stimulus ($\bar{X}=402.84$) were significantly ($p < .001$) shorter than those to the 0.00 stimulus in the same run ($\bar{X}=452.84$), and significantly ($p < .001$) shorter than the reaction times to both stimuli in both Runs 1 and 2. In addition, while the reaction times to 0.00 did not differ significantly from Run 1 to Run 2, they were significantly ($p < .001$) shorter in Run 3 than in both previous runs.

Discussion

Our findings indicate that event-related potentials obtained to equiprobable, task-relevant stimuli with differential incentive values result in different Factor 1 scores (P3 component) and LCA P3 amplitudes. The event-related potentials to these stimuli were not significantly different from each other during the initial baseline run. However, when the identical stimuli were presented, and the subjects were given the opportunity to earn money by accurately pressing the appropriate buttons, stimuli with high incentive value evoked significantly larger P3 component amplitudes than stimuli with low incentive value. This result was obtained under both Accuracy/Incentive and Speed-Accuracy/Incentive conditions. This finding is limited to the P3 component and does not obtain for any other component.

It should be noted that the P3 amplitude obtained to both stimuli is significantly larger in the Speed-Accuracy/Incentive condition than in the Accuracy/Incentive condition. This may well reflect the fact that there were significant task differences between the two runs, namely speed. In the Accuracy/Incentive condition, subjects could easily earn one dollar each time the 1.00 stimulus was presented by pressing the appropriate button while a dollar would be lost by incorrect presses to either stimulus. It is important to note that ample time was given to perform this very easy task, since only accuracy was stressed. In the Speed-Accuracy run, the subjects could only earn one dollar to the 1.00 stimulus if reaction times were kept below a criterion time. If reaction time to either stimulus was longer than this criterion time, the subject would lose a dollar. Thus performance to both stimuli was critical in enabling the subject to earn any money in this run. The response time criterion imposed on both stimuli in the Speed condition resulted in a significant increase in the motivational value of the stimuli relative to the excessively easy task required in the Accuracy condition. The result is significantly larger P3 amplitudes to both stimuli in Run 3 as compared to the same stimuli in Run 2. Our findings indicate that reaction times between stimulus 0.00 and stimulus 1.00 differed during both incentive conditions (Accuracy/Incentive, Speed-Accuracy/Incentive conditions) but not during baseline. These data suggest that response times varied with the incentive value of stimuli; shorter response times were obtained to stimuli yielding money. It should be noted that reaction times to stimulus 1.00 decreased significantly across the three conditions, while response times for stimulus 0.00 decreased significantly between the Accuracy condition and the Speed-Accuracy condition only.

It has been reported (Kutas et al., 1977; Ritter et al., 1972; McCarthy & Donchin, 1981) that under some conditions, the latency of the P3 component and reaction time may covary. While our present reaction time data indicate some significant differences, it should be noted that we did not observe any significant differences in P3 latencies across any conditions or stimuli. In order to assess whether the P3 differences obtained across conditions with the use of Principal Components Analysis could possibly be attributed to differential P3 variability, we subjected our data to Latency Corrected Averaging (LCA). Our P3 findings obtained subsequent to LCA indicate that our between-condition effects are not due to latency jitter but reflect voltage differences due to stimulus incentive values.

The results of our study strongly support the concept that the P3 amplitude of the event-related potential indexes stimulus significance. In the present study it was the motivational properties of the stimuli that determined P3 amplitude, since the stimuli were equal in all other respects (e.g. frequency, task-relevance). Sutton et al. (1978) suggested that rare unexpected stimuli or task-relevant stimuli may have inherently greater subjective value than commonly occurring task-irrelevant stimuli. Indeed there are a number of experimental procedures which have been used to vary the subjective value of a stimulus. Unexpected or uncertain stimuli have been shown to elicit large P3 amplitudes. Tueting et al. (1970) reported that the amplitude of the P3 component was inversely related to event probability. Duncan-Johnson and Donchin (1977) demonstrated that P3 amplitude was inversely proportional to the *a priori* probability of stimuli. Asking a subject to press a button to a specific stimulus (task relevance) increases the subjective value of that stimulus which results in a larger P3 amplitude (Roth, Ford, & Kopell, 1978). The motor response per se does not appear to have a significant effect on the P3 amplitude (McCarthy & Donchin, 1976). Hillyard, Squires, Bauer, and Lindsay (1971) obtained increased P3 amplitudes to stimuli which subjects had to discriminate and count; the subjects were not asked to make a motor response yet large P3 amplitudes were obtained to stimuli with high subjective value. Thus, stimulus uncertainty and task-relevance have both been shown to influence the amplitude of P3. More recently another cognitive process has been implicated as a possible index of the P3 component. Ruchkin and Sutton (1978) have proposed that the amplitude of P3 is in part determined by the process of equivocation, indexing the amount of information received by a subject. In information theory terms, the amount of information received by a subject depends upon the *a priori* probability of stimulus occurrence minus an information loss due to uncertainty or equivocation.

While the role of cognitive processes has been greatly emphasized in relation to P3 amplitude, it has not been demonstrated how much such processes can be clearly delineated from other critical processes occurring in the organism. Great emphasis on cognition has resulted in the neglect of other non-cognitive processes as potentially important determinants of P3 amplitude, particularly the incentive or motivational value of stimuli. The cognitive process of determining the "meaning" or "significance" of stimuli must of necessity possess a fundamental and critical emotive aspect. Several years ago, Sherrington (1940) asserted that "every cognition has, potentially at least, an emotive value, and, along with that, conative effort as a further factor." Complex cognitive processes, therefore, involve differing degrees of emotionality. Our present findings indicate that stimuli which are all equiprobable and task-relevant elicit differential amplitudes of the P3 component depending on the incentive or motivational value of stimuli.

It has been suggested that the analysis of the motivational content of stimuli may be associated with limbic system activity (Fuster & Uyeda, 1971). Recently, Halgren, Squires, Wilson, Rohrbaugh, Babb, and Crandall (1980) have implicated the hippocampus and amygdala as possible generators of the scalp-recorded P3 component. The limbic system may indeed in some, however limited capacity, be involved in the production of P3. Therefore, it may be postulated that this late positive component indexes the subjective motivational properties of stimuli. In this regard it is interesting to note that the P3 amplitude is quite low in anhedonic individuals (Simons, 1982), and in patients with aberrant levels of motivation (Roth, Pfefferbaum, Horvath, Berger, & Kopell, 1980; Porjesz, Begleiter, & Samuelly, 1980), as compared to control subjects.

Moreover, if P3 indexes the subjective motivational properties of stimuli, it is reasonable to assume that events which elicit a P3 will be remembered better than those events which do not elicit a P3. This is illustrated with some preliminary data from Donchin's laboratory indicating that there is a relationship between the amplitude of P3 and the memorability of the eliciting stimuli (Donchin, 1981).

A myriad of cognitive processes have been invoked to explain the functional significance of the P3 component (Donchin, 1979). Perhaps only insofar as a certain cognitive process is involved in making the stimulus significant to the organism does it affect P3 amplitude. Our findings suggest that the P3 component may well index the subjective motivational properties of environmental stimuli.

REFERENCES

Aunon, J.I., & McGillem, C.D. Detection and processing of individual components in the VEP. *Psychophysiology*, 1979, *16*, 71–79.

Donchin, E. Event related brain potentials: A tool in the study of human information processing. In H. Begleiter (Ed.), *Evoked brain potentials and behavior*. New York: Plenum Press, 1979. Pp. 13–88.

Donchin, E. Surprise! Surprise? *Psychophysiology*, 1981, *18*, 493–513.

Donchin, E., Ritter, W., & McCallum, W.C. Cognitive psychophysiology: The endogenous components of the ERP. In E. Callaway, P. Tueting, & S.H. Koslow (Eds.), *Event-related brain potentials in man.* New York: Academic Press, 1978. Pp. 349–412.

Duncan-Johnson, C.C., & Donchin, E. On quantifying surprise: The variation of event-related potentials with subjective probability. *Psychophysiology,* 1977, *14,* 456–467.

Ford, J.M., Roth, W.T., & Kopell, B.S. Auditory evoked potentials to unpredictable shifts in pitch. *Psychophysiology,* 1976, *13,* 32–29.

Friedman, D., Vaughan, Jr., H.G., & Erlenmeyer-Kimling, L. Stimulus and response related components of the late positive complex in visual discrimination tasks. *Electroencephalography & Clinical Neurophysiology,* 1978, *45,* 319–330.

Friedman, D., Vaughan, Jr., H.G., & Erlenmeyer-Kimling, L. Multiple late positive potentials in two visual discrimination tasks. *Psychophysiology,* 1981, *6,* 635–649.

Fuster, J., & Uyeda, A. Reactivity of limbic neurons of the monkey to appetitive and aversive signals. *Electroencephalography & Clinical Neurophysiology,* 1971, *30,* 281–293.

Halgren, E., Squires, N.K., Wilson, C.L., Rohrbaugh, J.W., Babb, T.L., & Crandall, P.H. Endogenous potentials generated in the human hippocampal formation and amygdala by infrequent events. *Science,* 1980, *210,* 803–805.

Hillyard, S.A., Picton, T.W., & Regan, D. Sensation, perception and attention: Analysis using ERP's. In E. Callaway, P. Tueting, & S.H. Koslow (Eds.), *Event-related brain potentials in man.* New York: Academic Press, 1978. Pp. 223–322.

Hillyard, S.A., Squires, K.C., Bauer, J.W., & Lindsay, P.H. Evoked potential correlates of auditory signal detection. *Science,* 1971, *173,* 1357–1360.

Homberg, V., Grünewald, G., & Grünewald-Zuberbier, E. The variation of P300 amplitude in a money-winning paradigm in children. *Psychophysiology,* 1981, *18,* 258–262.

Jennings, J.R., & Wood, C.C. The ϵ-adjustment procedure for repeated measures analysis of variance. *Psychophysiology,* 1976, *3,* 277–278.

Johnston, V.S. Stimuli with biological significance. In H. Begleiter (Ed.), *Evoked brain potentials and behavior.* New York: Plenum Press, 1979. Pp. 1–12.

Kutas, M., McCarthy, G., & Donchin, E. Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. *Science,* 1977, *197,* 792–795.

McCarthy, D., & Donchin, E. The effects of temporal and event uncertainty in determining the waveforms of the auditory event-related potential (ERP). *Psychophysiology,* 1976, *13,* 581–591.

McCarthy, D., & Donchin, E. A metric for thought: A comparison of P300 latency and reaction time. *Science,* 1981, *211,* 77–80.

McGillem, C.D., & Aunon, J.I. Measurements of single components in single visually evoked brain responses. *IEEE-BME,* 1977, *24,* 232–241.

Porjesz, B., Begleiter, H., & Samuelly, I. Cognitive deficits in chronic alcoholics and elderly subjects assessed by evoked brain potentials. *Acta Psychiatrica Scandinavica,* 1980, *62*(Suppl. 286), 15–29.

Pritchard, W.S. Psychophysiology of P300. *Psychological Bulletin,* 1981, *89,* 506–540.

Ritter, W., Simson, R., & Vaughan, Jr., H.G. Association cortex potentials and reaction time in auditory discrimination. *Electroencephalography & Clinical Neurophysiology,* 1972, *33,* 547–555.

Roth, W.T., Ford, S.M., & Kopell, B.S. Long-latency evoked potentials and reaction time. *Psychophysiology,* 1978, *15,* 17–23.

Roth, W.T., Pfefferbaum, A., Horvath, T.B., Berger, P.A., & Kopell, B.S. P3 reduction in auditory evoked potentials of schizophrenics. *Electroencephalography & Clinical Neurophysiology,* 1980, *49,* 497–520.

Ruchkin, D.S., & Sutton, S. Emitted P300 potentials and temporal uncertainty. *Electroencephalography & Clinical Neurophysiology,* 1978, *45,* 268–277.

Sherrington, R. *Man and his nature.* London: Cambridge University Press, 1940.

Simons, R.F. Physical anhedonia and future psychopathology: An electrocortical continuity? *Psychophysiology,* 1982, *19,* 433–441.

Squires, K.C., Donchin, E., Herning, R.I., & McCarthy, G. On the influence of task relevance and stimulus probability on event-related potential components. *Electroencephalography & Clinical Neurophysiology,* 1977, *42,* 1–14.

Squires, N.K., Squires, K.C., & Hillyard, S.A. Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography & Clinical Neurophysiology,* 1975, *38,* 387–401.

Sutton, S. P300—Thirteen years later. In H. Begleiter (Ed.), *Evoked brain potentials and behavior.* New York: Plenum Press, 1979. Pp. 107–126.

Sutton, S., Braren, M., Zubin, J., & John, E.R. Evoked potential correlates of stimulus uncertainty. *Science,* 1965, *150,* 1187–1188.

Sutton, S., Tueting, P., & Hammer, M. Evoked potentials and feedback. In D.A. Otto (Ed.), *Multidisciplinary perspectives in event related brain potential research.* EPA-60019-77-043. Washington, DC: U.S. Government Printing Office, 1978. Pp. 184–188.

Tueting, P. Event-related potentials, cognitive events, and information processing. In D.A. Otto (Ed.), *Multidisciplinary perspectives in event related brain potential research.* EPA-60019-77-043. Washington, DC: U.S. Government Printing Office, 1978. Pp. 159–169.

Tueting, P., Sutton, S., & Zubin, J. Quantitative evoked potential correlates of the probability of events. *Psychophysiology,* 1970, *7,* 385–394.

Winer, B.J. *Statistical principles in experimental design.* New York: McGraw-Hill Book Company, 1971.

REFERENCE NOTE

1. McGillem, C.D., Aunon, J.I., & Pomalaza, C. *Improved waveform estimation procedures for event related potentials.* Manuscript in preparation.

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