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ATTENTION, PROBABILITY, AND TASK DEMANDS AS DETERMINANTS OF P300 LATENCY FROM AUDITORY STIMULI [1]

JOHN POLICH

Division of Preclinical Neuroscience and Endocrinology, Scripps Clinic and Research Foundation, La Jolla, CA 97037 (U.S.A.)

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Summary A series of 3 experiments investigated factors which could affect the morphological quality and latency of the P3 ERP component from auditory stimuli. Manipulations of attention and probability of the target tone changed P3 amplitude but typically demonstrated little effect on P3 latency. No differences for either component measure were obtained when recordings were made with the subjects' eyes open or closed. Passively ignoring the stimulus items decreased P3 amplitude and increased its latency relative to active stimulus discrimination.

Keywords: *P300 – latency – ERPs – attention – probability*

The P300 or P3 component of the event-related brain potential (ERP) is beginning to demonstrate considerable utility as a clinical tool for the assessment of cognitive function. Initial applications found that latency of the P3 becomes longer with increases in adult age (Goodin et al. 1978b; Syndulko et al. 1982; Brown et al. 1983; Pfefferbaum et al. 1984a; Picton et al. 1984; Polich et al. 1985a), and increases substantially with mental dysfunction such as retardation (Squires et al. 1979) and dementing illness (Brown et al. 1982; Goodin et al. 1978a; Hansch et al. 1982; Lai et al. 1983; Pfefferbaum et al. 1984b; Polich et al. 1986). Additional studies have suggested that shorter P3 latencies are associated with relatively superior memory performance in neurologically normal subjects (Polich et al. 1983; Howard and Polich 1985), and that changes in the P3 component can originate from fluctuations in cognitive state (Goodin et al. 1983), amount of alcohol typically consumed (Polich 1984; Polich and Bloom 1986), and individual differences in memory retrieval (Karis et al. 1984). Thus, the P3 ERP component is becoming a viable measure for assessing variations in cognitive function in a variety of normal and neuropsychologically interesting populations.

A simple two-tone discrimination paradigm often has been used to elicit the P3 in many of these studies. This procedure typically involves the presentation of auditory stimuli with one occurring less frequently than the other, and the subject required to count mentally or press a button whenever the infrequent or target stimulus is presented. Although many studies have examined changes in P3 latency with complex information processing paradigms (e.g., Ritter et al. 1979; Duncan-Johnson 1981; McCarthy and Donchin 1981; Parasuraman et al. 1982), only a few reports are available concerning pertinent task variables which may contribute to variations in P3 latency obtained with the auditory 'oddball' paradigm typically employed in clinical testing. Sklare and Lynn (1984) examined the replicability of P3 latency within subjects across measurement trials and found only small changes in trial-to-trial testing during an experimental session or after several

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weeks. Papanicolaou et al. (1985) manipulated stimulus intensity and observed decreases in P3 latency as loudness increased. Polich et al. (1985b) varied target tone frequency relative to a constant standard tone and found decreases in P3 latency as the frequency separation increased; presentation of a white noise masking stimulus further increased peak latency at a constant rate across tone separation conditions. Little else has been reported which systematically related potentially important presentation variables and changes in P3 latency with a simple two-tone stimulus procedure.

The present experiments were designed to provide additional information about the production of the P3 ERP component from auditory stimuli in an oddball task situation. The underlying rationale guiding the choice of experimental variables stemmed from the application of the auditory discrimination task to cognitively disabled subjects. Because such individuals demonstrate fluctuations in concentration, may not tolerate long recording sessions, and have difficulty maintaining a stable body posture, ERP measurement situations were designed which would mimic some of these conditions in cognitively able individuals. Moreover, since P3 latency has been of primary interest in clinical recordings, task variables which change P3 amplitude were chosen so that their effects on P3 latency could be explicitly studied. A simple oddball paradigm was employed across experiments. This task simultaneously varied the frequency and intensity of the target tone to effect a very easy stimulus discrimination. Such an approach has been used previously with demented populations (Brown et al. 1982; Polich et al. 1986) and was employed here in order to investigate how various processing conditions would affect the P3 response in normal subjects.

Methods

Subjects

Each experiment employed 12 undergraduate students who reported no neurological or psychiatric disorders. Different groups of subjects were obtained for each study, and all subjects received course credit for their participation. Subjects were 18–24 years old (mean = 20.2 years) with similar proportions of each sex used in each study. This population was chosen to obtain baseline data which could be compared with other subject groups (e.g., aged, demented, etc.).

Recording conditions

ERPs were elicited with binaural 1000 and 2000 Hz tones at 50 and 65 dB SPL having 9.9 msec rise/fall and 50 msec plateau times. The tones were presented in a random series once every 2 sec, with the low/soft tone always designated as the standard and the high/loud tone always designated as the target stimulus. Variations in task requirements and stimulus presentation conditions across experiments are described below.

Electroencephalographic activity was recorded at the Fz, Cz, and Pz electrode sites of the 10-20 system using gold-plated electrodes affixed with electrode paste and tape and referred to linked earlobes with a forehead ground. Additional electrodes were placed at the outer canthus and supraorbitally to the left eye with a bipolar recording made of the EOG. Impedance for all recording sites was 10 kΩ or less. The filter bandpass was 0.5–30 Hz (3 dB down, 12 dB octave/slope). The EEG was digitized at 1.5 msec per point for 768 msec with a 75 msec prestimulus baseline. Wave forms were averaged on-line by an apparatus which also controlled the stimulus presentation and artifact rejection. Trials on which the EEG or EOG exceeded ± 45 μV were automatically rejected.

Procedures

Experiment 1. The effects of graded changes in subject attention to the eliciting stimuli on the P3 component were assessed in 3 different conditions. Subjects were instructed either (1) to keep a mental *count* of the number of target tones presented, (2) to *ignore* all the tones by purposely thinking of something else or daydreaming, or (3) to *read* from a text and be prepared to answer questions about the material. Task conditions were presented in a counterbalanced order across subjects. Target tones occurred on 10% of the trials with a minimum of 2 standard tones presented between targets and a total of 30 artifact-free target trials obtained for each experimental condition. All recordings were made with the subjects sitting upright in a comfortable chair and eyes kept open.

Experiment 2. The effects of changes in stimulus probability on the P3 were measured by presenting target tones at 5%, 10%, or 20% rates in separate blocks such that a target could occur on any given stimulus presentation. A total of 20 target trials were obtained for each condition. To explore further the possibility of obtaining reliable P3 components from subjects who were not engaged in an explicit stimulus discrimination task, these probability levels were presented under active and passive response conditions. During the *active* task condition, subjects tapped their finger to the occurrence of a target tone whilst sitting upright with their eyes closed. During the *passive* task condition, subjects were instructed to ignore all the tones and rest comfortably while lying down on a hospital bed with their eyes closed. They were cautioned not to sleep but to remain awake and think. Compelling verbal reminders were provided periodically to facilitate continued maintenance of an awake state. All 3 probability rates were recorded under each response mode and counterbalanced across subjects, with half the subjects receiving the active condition first and half the subjects receiving the passive condition first.

Experiment 3. Task demands and subject state were manipulated by presenting stimulus sequences with the subject engaged in an *active* finger-tapping discrimination task while sitting or in a *passive* state while lying down. Each of these task and body position conditions was performed twice, once with *eyes open* and once with *eyes closed*. Each subject received all 4 conditions which were presented in a block randomized fashion across subjects. Before each passive condition, subjects rested for several minutes on the bed to induce a semi-drowsy state so that the effects of these conditions on the P3 component could be assessed. Subjects were cautioned to remain awake and monitored verbally to ensure that they did not doze. Target tones occurred randomly on 20% of the trials with a minimum of 2 standard tones presented between any 2 target tones. Because a subject's state might vary over time, a total of 200 tones were presented in each experimental condition to ensure that the same amount of time was spent in each condition; 35–45 target trials were thus recorded in each session.

Results

P3 measurement

Task performance (count and finger-tapping) was virtually perfect with fewer than 1.5% of the target trials misperceived across experiments. Hence, the obtained ERPs were comprised of essentially all correctly processed stimulus trials. Wave forms from each condition of all 3 experiments were measured in the same fashion: the largest positive-going peak occurring after the N1–P2–N2 complex between 250 and 400 msec was designated as the P3 component. Amplitude was measured relative to the prestimulus baseline with peak latency defined as the time point of maximum positive amplitude. These data points were then employed for statistical analyses.

Experiment 1

The ERP wave forms for each attention condition and recording site averaged over all subjects from the first experiment are illustrated in Fig. 1. The mean amplitude and latency for each condition across electrode sites are presented in Fig. 2. As is apparent from the wave form data, diversion of the subject's attention from the stimulus sequence yielded decreases in overall P3 amplitude, although little change for P3 latency was obtained. A 2-factor (attention condition × electrode site) analysis of variance performed on the P3 amplitude data revealed a significant main effect for the attention manipulation, with $F\ (2, 22) = 6.5$, $P < 0.01$. The frontal-to-parietal increase in P3 amplitude typically observed was also found in these data, $F\ (2, 22) = 6.4$, $P < 0.01$, although no reliable interaction between amplitude and electrode site was obtained ($P > 0.10$). Separate one-way analyses comparing the attention condition for each electrode site indicated that the attention effect was significant for both the Cz and Pz scalp

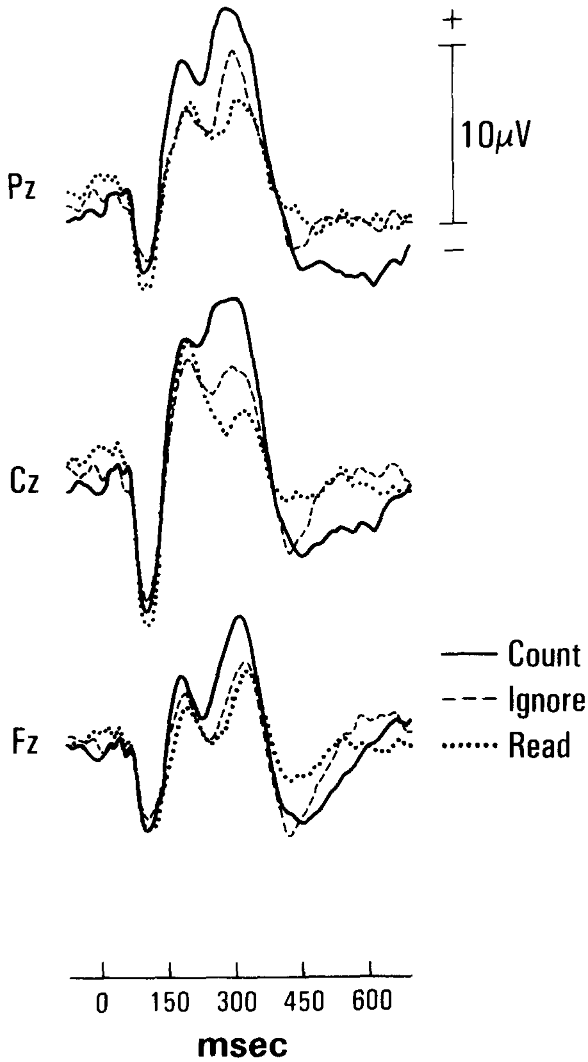

Fig. 1. ERPs illustrating the P3 components from the Fz, Cz, and Pz electrode sites for the count, ignore and reading task conditions (experiment 1).

locations ($P < 0.01$), but not for the Fz site ($P = 0.08$).

An identical analysis of the P3 latency data indicated that the decrease of P3 latency apparent in Fig. 2 from the frontal-to-parietal electrode sites was significant, with F (2, 22) = 3.5, $P < 0.05$. No other significant effects were obtained for this or the separate electrode site analysis used to assess attentional effects on P3 latency.

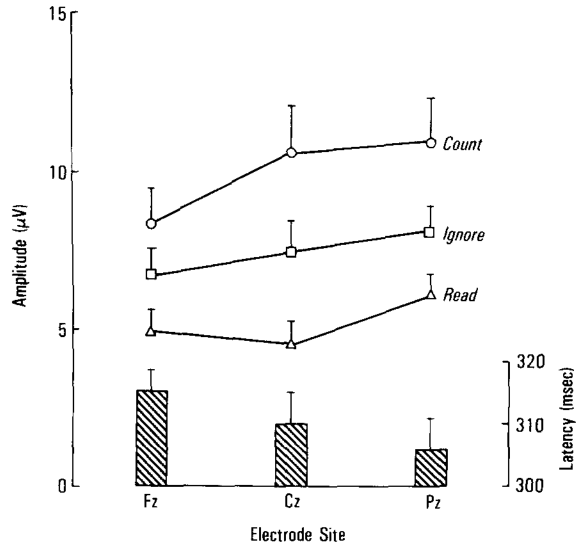

Fig. 2. Mean P3 amplitude and one standard error for each experimental condition and recording site; bar graphs indicate mean P3 latency collapsed over task conditions and one standard error (experiment 1).

Experiment 2

The ERP wave forms for each probability, task condition, and recording site averaged over all subjects from the second experiment are illustrated in Fig. 3. The mean amplitude and latency data collapsed over the probability manipulations are presented in Fig. 4. These figures suggest that little difference in overall P3 amplitude or latency was obtained as the probability of the target stimulus was varied from 5%, 10%, to 20% in the active task condition. P3 amplitude was dramatically affected when no overt discrimination task requirements were imposed, although the 5% target presentation rate in the passive condition does appear to yield an identifiable P3 component, especially at the Pz electrode site. Preliminary analysis of variance indicated that whether the subjects received the active or passive condition first produced no significant effects for either the amplitude or latency measures.

A 3-factor (target probability × response task × electrode site) analysis of variance was performed on the P3 amplitudes obtained for each condition from each subject. No reliable effects of target probability were obtained ($P > 0.70$), nor

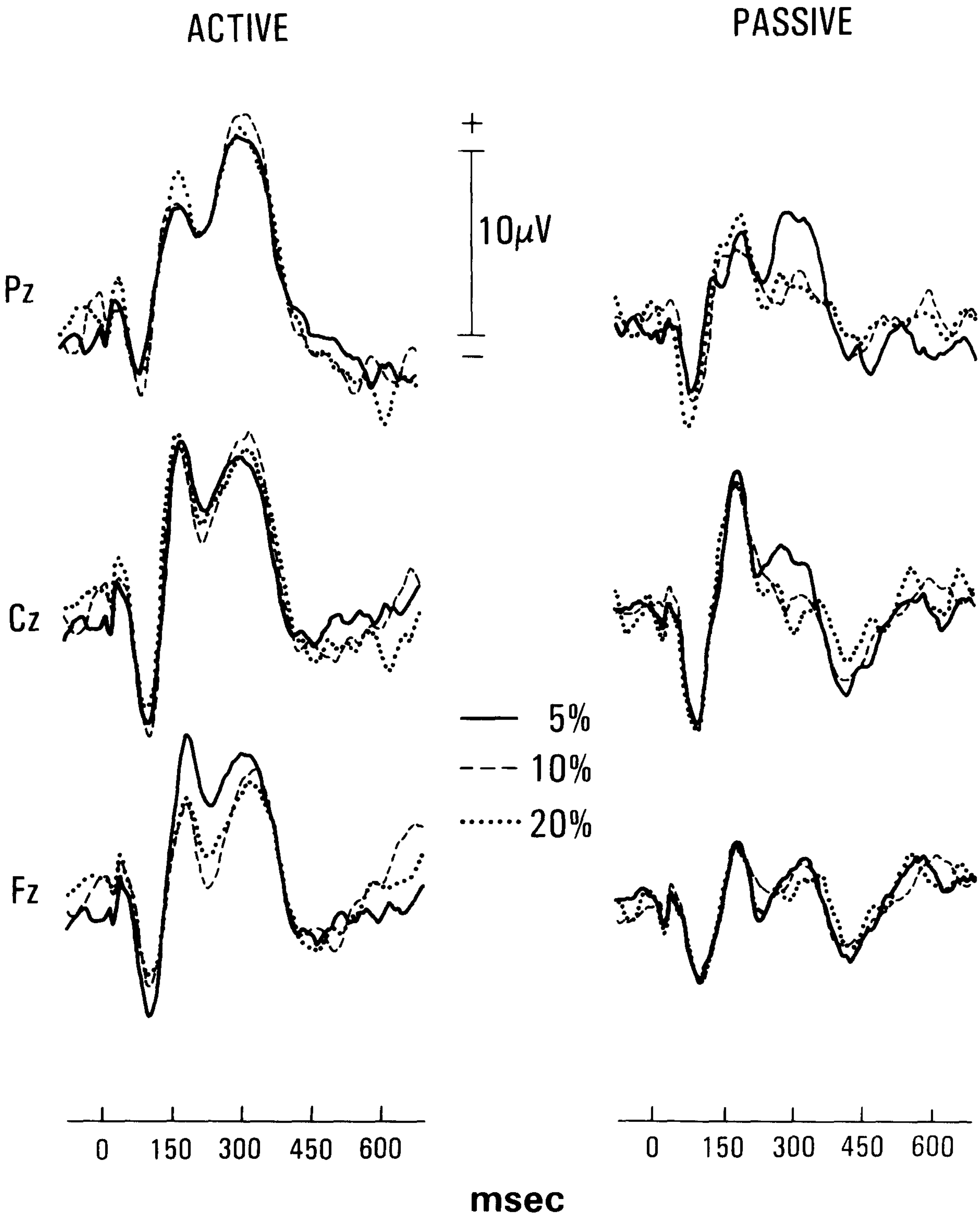

Fig. 3. Grand averaged ERPs illustrating the P3 components from the Fz, Cz, and Pz electrode sites for each probability and response task condition (experiment 2).

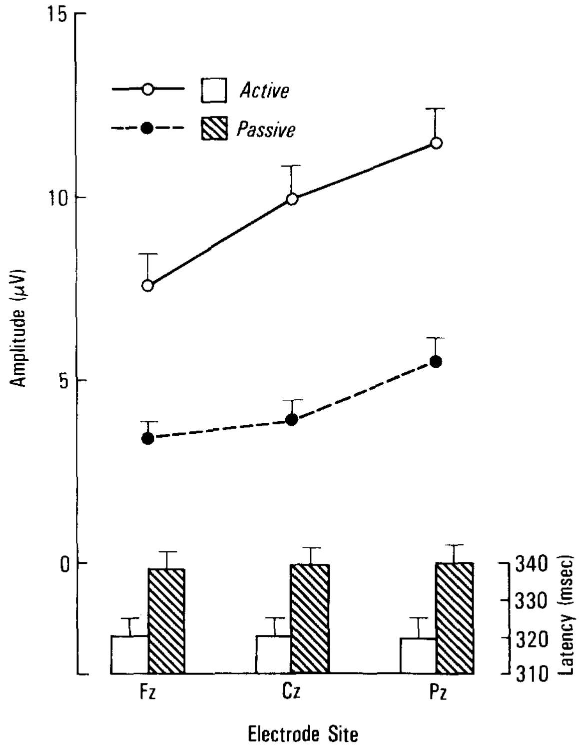

Fig. 4. Mean P3 amplitudes and latencies and one standard error for each recording site collapsed over target tone probability for each response task condition (experiment 2).

did this factor interact significantly with any other variable ($P > 0.20$). As is apparent in Fig. 4, the active response task condition produced significantly larger P3 components than the passive response task condition, F (1, 11) = 14.6, $P < 0.01$, and component amplitude increased significantly from the frontal-to-parietal electrode sites, F (2, 22) = 18.8, $P < 0.001$. Neither of these factors interacted with any experimental variables. The same pattern of statistical outcomes for the amplitude data were obtained when each response task data set (i.e., active and passive) was analyzed separately.

An identical analysis performed on the P3 latency data revealed no significant effects for probability of the target stimulus ($P = 0.17$), although there was a tendency for latency to increase as target probability increased from 5%, 10%, to 20% for both the active (317, 315, 329 msec) and passive (334, 336, 344 msec) task conditions. None of the interactions between this factor and any other variable ($P > 0.60$) were significant. Only the mean latency difference between the active and passive task conditions (320 vs. 339 msec) was significant, with F (2,11) = 6.6, $P <$ 0.05. Analyses performed separately on the active and passive response conditions confirmed the impression gleaned from Fig. 4 that target probability produced no significant effects for peak P3 latency for any of the electrode sites ($P > 0.15$).

Experiment 3

The ERP wave forms for task demands and eyes open/closed response conditions averaged over subjects from the third experiment are presented in Fig. 5, with the mean P3 amplitude and latency values plotted in Fig. 6. The data of Fig. 5

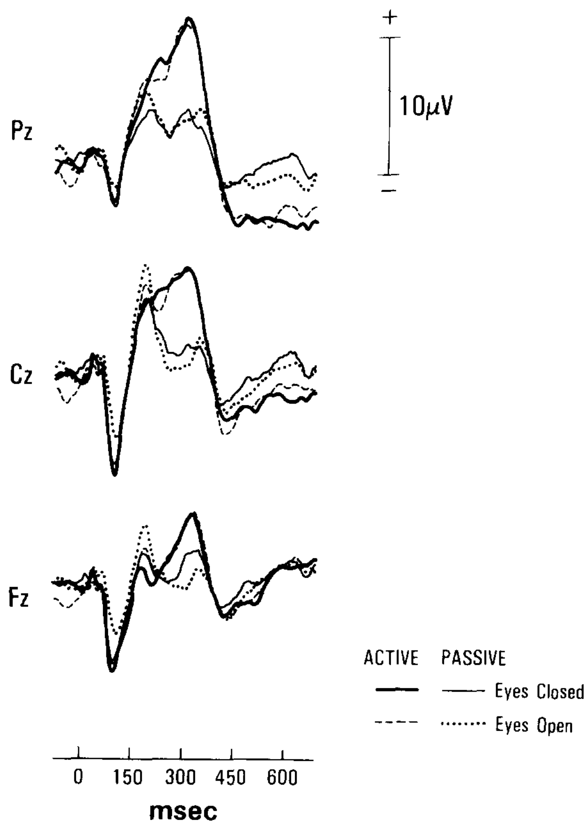

Fig. 5. Grand averaged ERPs illustrating the P3 components from the Fz, Cz, and Pz electrode sites for each response task and eyes open/closed condition (experiment 3).

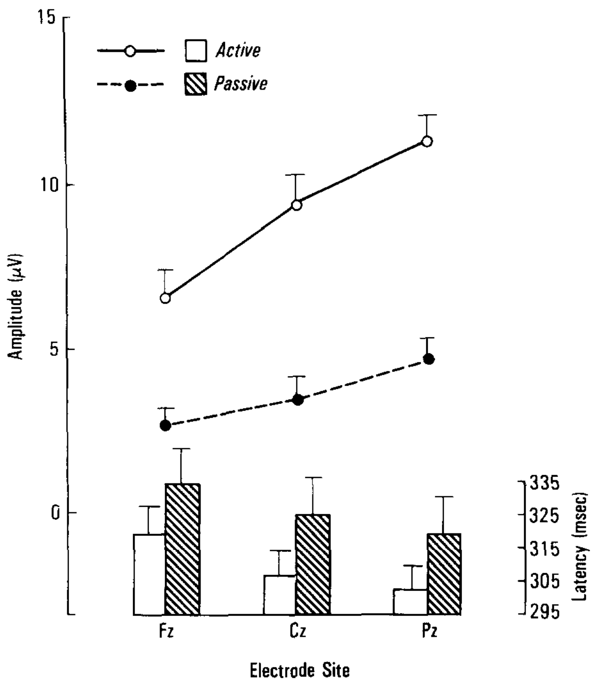

Fig. 6. Mean P3 amplitudes and latencies and one standard error for each recording site collapsed over the eyes open/closed for each response task condition (experiment 3).

suggest that whether the subjects eyes were opened or closed made little difference for either the P3 amplitude or latency values. Task response requirements, however, again produced substantial effects on both the amplitude and latency responses as illustrated in Fig. 6. As suggested below by the separate analyses of variance performed on the active and passive conditions, the counterbalanced presentation of these manipulations produced no differential amplitude or latency changes due to order effects.

A 3-factor (eye position × response task × electrode site) analysis of variance was performed on the P3 amplitude data obtained from each subject for each condition. Whether the subject's eyes remained opened or closed had no effect on P3 amplitude ($P > 0.70$) or any other variable ($P > 0.50$). Again, response task and electrode site yielded significant main effects, with F (1, 11) = 25.6, $P < 0.001$ and F (2, 22) = 26.4, $P < 0.001$, respectively. No other significant results were obtained, and the same pattern of outcomes was found when each response task data set was analyzed separately.

An identical analysis performed on the P3 latency data also found no differences for the eyes open/closed manipulation or any interaction between this and the other experimental variables ($P > 0.30$). As indicated by Fig. 6, however, response task and electrode site yielded significant main effects, F (1, 11) = 11.1, $P < 0.01$ and F (2, 22) = 14.6, $P < 0.001$, respectively. No other effects for P3 latency were obtained when each response task data set was analyzed separately with each set demonstrating similar patterns.

Discussion

Taken together, these results suggest that the amplitude of the auditory P3 component is affected by variables which can influence the quality or certainty of the discrimination between the standard and target tone stimuli: how conscientiously the subject is engaged in the task situation appears to be the primary factor governing amplitude size (Sutton 1979; Donchin 1981). However, if the stimuli are segregated into their standard and target categories with even a modicum of attention, relatively little change in P3 latency is observed under a variety of different recording conditions. Thus, fluctuation in attention as mimicked by the count, ignore and reading tasks of experiment 1, while changing component amplitude systematically, did not significantly affect peak latency. Similarly, variations in target probability from 5% to 10% to 20% in experiment 2 did not affect P3 latency substantially, although a tendency toward increased latency (about 10–15 msec) was observed with increases in target probability. Comparison of the eyes open vs. eyes closed ERPs in experiment 3 also demonstrated no significant effects for either P3 amplitude or latency.

The major change in P3 latency observed in the present studies occurred whenever the demands of the auditory task situation were minimized under the passive conditions of experiments 2 and 3. In these cases, subjects were explicitly instructed to ignore the tone sequence by daydreaming while they were in a relaxed, horizontal position. The passive response and prone posture substantially decreased P3 amplitude and yielded delays on the order of 10–20 msec across experimental conditions. Although it can be argued that no P3 component should have been obtained under these circumstances, the change in frequency and intensity of the target (2000 Hz/65 dB) relative to the standard stimulus (1000 Hz/50 dB) apparently coerced some amount of stimulus discrimination in most subjects to produce an observable P3 wave form even under passive response conditions (see Figs. 3 and 5). These stimulus parameters were chosen explicitly to assess the feasibility of obtaining reliable P3 components under very minimal task requirements to determine their efficacy when applied to uncooperative, cognitively dysfunctional populations (e.g., Squires et al. 1979; Brown et al. 1982; Polich et al. 1986). The weak response obtained coupled with the substantially delayed latency in normal subjects make this approach a poor substitute for an active discrimination task situation.

These findings support the general conclusions obtained in previous studies (Sklare and Lynn 1984; Papanicolaou et al. 1985; Polich et al. 1985b): P3 latency is reasonably stable and varies relatively little as a function of task variables when the subject is engaged in an explicit discrimination paradigm. The largest decreases in component amplitude and increases in peak latency were always observed in those conditions in which a passive reception of the stimulus train was employed. Thus, application of the P3 ERP in clinical and evaluative testing situations should emphasize stimulus discrimination, although fluctuations in attention, probability of the eliciting stimulus, and whether the eyes are kept open or closed appear to have relatively little effect on P3 latency.

Résumé

Attention, probabilité et exigences du test sont déterminants dans la latence de P300 à un stimulus auditif

Une série de 3 expériences a été effectuée pour rechercher les facteurs pouvant affecter la qualité de forme et la latence de la composante P3 de l'ERP à un stimulus auditif. Des modulations de l'attention et de la probabilité d'apparition du son-cible ont modifié l'amplitude de P3 avec pratiquement aucun effet sur sa latence. Aucune différence n'a été observée pour les deux paramètres de la P3, que les enregistrements aient été effectués chez des sujets yeux fermés ou yeux ouverts. L'ignorance passive du stimulus a diminué l'amplitude de P3 et augmenté sa latence par rapport à une discrimination active du stimulus.

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