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STIMULUS FREQUENCY AND MASKING AS DETERMINANTS OF P300 LATENCY IN EVENT-RELATED POTENTIALS FROM AUDITORY STIMULI *

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The effects of target tone frequency, presence of a masking stimulus, and subject sex on the auditory ERP were studied with an 'oddball' paradigm. P300 latency became shorter (about 15 msec) as the difference between the standard (1000 Hz) and target tone frequency increased (1500, 2000, 4000 Hz) but became longer (about 10 msec) with the presence of a white noise masking stimulus. Similar results were obtained for both the P3a and P3b subcomponents of the P300 potential. No significant differences between the adult male and female subjects were observed. The role of stimulus parameters in applied testing situations is discussed.

1. Introduction

The P300 component of the event-related brain potential (ERP) is a large (5–15 μ V), positive-going waveform that occurs with a modal latency of about 300 msec in normal young adults. Although the neurophysiology underlying the P300 is still being explored (Halgren, Squires, Wilson, Rohrbaugh, Bab and Crandall, 1980; Okada, Kaufman and Williamson, 1983), the cognitive events associated with its generation have received considerable attention (Donchin, 1981; Donchin, Ritter and McCallum, 1978; Pritchard, 1981). Because the

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P300 is thought to reflect stimulus evaluation and classification processes, it has found application in the assessment of cognitive function. In particular, its peak latency has been used to evaluate the effects of aging on cognition (Brown, Marsh and LaRue, 1983; Ford, Duncan-Johnson, Pfefferbaum and Kopell, 1982; Goodin, Squires, Henderson and Starr, 1978; Howard and Polich, 1985; Pfefferbaum, Ford, Roth and Kopell, 1980; Pfefferbaum, Ford, Wenegrat, Roth and Kopell, 1984; Picton, Stuss, Champagne and Nelson, 1984; Polich, Howard and Starr, in press; Smith, Michalewski, Brent and Thompson, 1980; Squires, Goodin and Starr, 1979; Syndulko, Hansch, Cohen, Pearce, Goldberg, Montan, Toutellotte and Potvin, 1982), as well as neurological and psychiatric disorders affecting mental functions (Brown, Marsh and LaRue, 1982; Canter, Hallett and Growdon, 1982; Goodin, Squires and Starr, 1978; Hansch, Syndulko, Cohen, Goldberg, Potvin and Tourtellotte, 1982; Litzelman, Thompson, Michalewski, Patterson and Bowman, 1980; Pfefferbaum et al., 1984; Polich, Ehlers, Otis, Mandell and Bloom, in press; Squires, Chippendale, Wrege, Goodin and Starr, 1980; Squires, Galbraith and Aine, 1979). Thus, P300 latency as an index of cognitive function is becoming an important and widespread tool in the assessment of mental capability.

A typical procedure employed in these investigations involves the presentation of two different signals, one less frequently than the other. The subject keeps a mental count or presses a button to the infrequent event and thereby discriminates the target stimulus from the background standard stimulus events. This so-called 'oddball' paradigm reliably produces the P300 component and has often been used to study factors which affect its amplitude (e.g. Duncan-Johnson and Donchin, 1977; Squires, Wickens, Squires and Donchin, 1976). The latency of the P300 has also been examined, typically by means of complex task situations involving visual stimuli (e.g. Kutas, McCarthy and Donchin, 1977; Duncan-Johnson and Kopell, 1981; McCarthy and Donchin, 1981; Polich, McCarthy, Wang and Donchin, 1983), with only a few studies using a simple auditory stimulus paradigm and reporting some normative latency data (e.g. Ford, Hink, Hopkins, Roth, Pfefferbaum and Kopell, 1979; Polich, Howard and Starr, 1983; Squires, Donchin, Squires and Grossberg, 1977). However, variations in the application of the oddball counting task may have produced some of the latency variability obtained across these studies, because differences in stimulus parameters could readily contribute to P300 latency by affecting the ease of stimulus categorization (Goodin, Squires and Starr, 1983; Fitzgerald and Picton, 1983; Magliero, Bashore, Coles and Donchin, 1984). To assess this possibility, the present studies employed an auditory oddball paradigm in which the frequency separation between the target and standard tone was varied in order to manipulate stimulus discriminability. Each stimulus tone frequency condition was also presented with and without a white noise background; this technique is often used to mask environmental sounds during ERP recording and may also affect task diffi-

culty (cf. McCarthy and Donchin, 1976; Squires, Donchin, Herning and McCarthy, 1977). In addition, subject sex, which affects the latencies of various sensory evoked potentials (e.g. Polich and Starr, 1983; Shucard, Shucard and Cummings, 1981; Stockard, Stockard, and Sharbrough, 1978), was controlled.

2. Methods

2.1. Subjects

A total of 24 volunteer subjects (12 of each sex) who ranged in age from 18–35 years were obtained from within the university community. All reported normal hearing and participated in one two-hour session.

2.2. Recording conditions

ERPs were elicited by presenting subjects with a series of binaural tones at 60 dB nHL with a 9.9 msec rise/fall and 50 msec plateau time. The tones were presented in a random sequence with the standard tone occurring 80% of the time and the target tone 20% of the time at a rate of 1.1/sec. Subjects were instructed to keep a silent count of the number of target tones (as defined below). Stimuli were presented until a block of 200 artifact-free trials was obtained for each condition. Electroencephalographic activity (EEG) was recorded between the vertex (Cz electrode site in the 10–20 system) referenced to linked mastoids with a forehead ground. The filter bandpass was 1–30 Hz (3 dB down, 12 dB/octave slope). Although not optimal, the relative latency of the P300 should be unaffected by this bandpass range even though component amplitude would be reduced compared to a longer time-constant (see Duncan-Johnson and Donchin, 1979; Polich et al., 1983). The EEG was digitized at 3 msec/point for 768 msec and averaged on line by a Nicolet CA-1000 that also controlled the stimulus presentation and automatic artifact rejection of the averaged channel. Trials on which the EEG exceeded $\pm 45 \mu\text{V}$ were automatically rejected and not included in the averaged waveform. Hence, only trials uncontaminated by eye blinks, eye movements, and muscle contractions that usually produce very large voltage fluctuations (typically greater than 100 μV) were recorded. Separate averages for the rare and frequent stimulus tones were plotted, with the latencies of the components defined at their peak or trough. Amplitudes were not measured.

2.3. Design and procedure

Subjects were placed in a sound-attenuating booth and instructed about the various stimulus conditions and the counting task. Each subject was then

presented with six different stimulus conditions. The frequent or standard tone was always 1000 Hz, whereas the rare or target tone was 1500, 2000, or 4000 Hz. These frequencies were chosen to ascertain the effects of target and standard frequency separation on P300 latency over a reasonable but practical range. Each combination of tones was presented with a masking stimulus of 60 dB nHL white noise (MASKED) or without a masking stimulus (CLEAR). The presentation order of the six conditions was block randomized across subjects. After each experimental condition, the subject's count of the number of target tones was obtained, and s/he was given a brief rest period before the next condition.

3. Results

3.1. Count task data

Because the computer accepted only trials on which the EEG was within 50 μ V of baseline, the number of trials each subject received varied for a given condition. An overall mean of 41.6 target tones was presented for each condition, but no statistical difference between the various conditions or subject groups was obtained ($F < 1$, for all main effects). Subjects were highly accurate in their target tone counts, missing the correct number on the average by 1.2 counts. No differences between any of the stimulus conditions or subject groups was obtained for the number of tones incorrectly counted or for the percentage of errors. It can be safely assumed, therefore, that subjects were sufficiently engaged by the task situation to produce accurate and consistent performance under all conditions.

3.2. Waveform data

Examples of the ERP data for all conditions are presented in fig. 1. These data are from four representative subjects and illustrate the potentials obtained for the six different conditions to both the rare (1500, 2000, and 4000 Hz) and frequent (1000 Hz) stimuli. The components are labelled in the middle two rows of the CLEAR stimulus condition and agree in morphology and latency range with previous reports. In most of the subjects, the P300 component from the target stimulus displayed two distinct subcomponents. These are labelled the P3a and P3b, with the former defined as the first positive-going potential occurring after the N2 between 220–280 msec, and the latter as the subsequent positivity occurring between 250–350 msec. Most often a bifurcated peak was observed for the same subject in the majority of recording conditions. If only a single positive peak was observed, it was labelled a P3b. While scalp distributions of these subcomponents could not be obtained, use of latency window

Fig. 1. Waveforms obtained from four different subjects (overplotted) for the standard (1000 Hz) and target tones (1500, 2000, 4000 Hz) in an auditory oddball paradigm. The CLEAR column illustrates waveforms collected when stimuli were presented without an auditory mask, while the MASKED column illustrates waveforms collected when stimuli were presented with a 60 dB white noise mask. Note the latency shift apparent in the P3a and P3b portion of the waveforms as a function of target tone frequency.

criteria and observation of the two subcomponents over task conditions within a subject facilitated component measurements and yielded similar results as those previously reported for the P3a and P3b varieties of the P300 potential (Ford, Roth and Kopell, 1976; Polich et al., 1983; Roth, 1973; Snyder and Hillyard, 1976; Squires, Squires and Hillyard, 1975).

Table 1
Mean latency (msec), standard deviation (SD), and number of subjects (N) demonstrating a P3a and P3b subcomponent in each stimulus condition

		1500 Hz		2000 Hz		4000 Hz	
		P3a	P3b	P3a	P3b	P3a	P3b
CLEAR	Mean	262	330	254	320	247	312
	SD	15.1	22.9	31.7	29.7	24.1	23.7
	N	22	24	21	24	22	24
MASKED	Mean	270	337	259	331	257	321
	SD	13.6	25.8	30.1	29.1	21.4	27.2
	N	22	24	22	24	23	24

The mean latencies and standard deviations of the P3a and P3b components from the target tone stimulus are presented in table 1 with the effects of task conditions illustrated in fig. 2. There was no statistical difference in the number of subjects yielding a P3 subcomponent across experimental conditions ($\chi^2 = 0.01$, $p > 0.9$), implying that the occurrence of a P3a and P3b was unrelated to the frequency of the target tone or the presence of a masking stimulus. As indicated by figs. 1 and 2, the P300 component complex occurred

Fig. 2. Mean P3a and P3b latency as a function of target tone frequency for the CLEAR and MASKED stimulus presentation conditions.

at shorter latencies as the difference between the standard and target tone frequencies increased. Some slowing of the P300 components also appears to occur when the white noise masker was presented compared to the clear condition.

The latencies of each subcomponent were subjected to a four-factor (Target Frequency $\times$ Masking Condition $\times$ Component Type $\times$ Subject Sex) analysis of variance. The mean latencies for the P3a component were used as data points for the few subjects not yielding such measures in a specific condition. This analysis confirmed the trends indicated above: As the target tone frequency increased, P300 latency decreased significantly ($F(2,44) = 12.7$, $p < 0.0001$) although the magnitude of effect was only about 15 msec. The presence of a white noise masking stimulus significantly delayed the latency of the P300 component(s) by about 10 msec ($F(1,22) = 5.4$, $p < 0.03$). The latencies of the P3a and P3b were also different ($F(1,22) = 474.1$, $p < 0.0001$). None of these variables were affected by subject gender ($p > 0.4$, in all cases), and no significant interactions were obtained.

4. Discussion

Changing the target tone frequency relative to the standard tone and use of a white noise masking stimulus produced consistent, albeit small effects on P3a and P3b latency (10–15 msec). No differences in latency were observed as a function of gender. In applied testing, the choice of auditory stimulus parameters should not greatly affect overall P300 latency. However, if the perceptual difference between the target and standard tones is very small so that discrimination between the two tones is relatively difficult, the latency of the P300 can increase by up to 50 msec (Ford et al., 1979; Goodin et al., 1983; Squires, et al., 1980). Hence, variations in stimulus parameters is important insofar as they help determine task discrimination difficulty and therefore affect the resulting P300 peak latency for a given population. The present results illustrate the range of these effects for values of typically employed auditory stimuli and indicate that subject sex does not critically affect latency of the P300 ERP component.

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