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P3a from visual stimuli: Task difficulty effects

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Abstract

The P3a event-related brain potential (ERP) was elicited using a visual three-stimulus oddball paradigm (target, standard, distracter) in which participants responded only to the target. Discrimination task difficulty between the target and the standard was manipulated by varying the size of the standard stimulus circle relative to a constant target stimulus circle across three conditions (easy, medium, hard). A large checkerboard pattern was employed for the distracter stimulus across all tasks. Error rate and response time increased with increases in task difficulty, so that the task difficulty manipulation was successful. Distracter P3a amplitude increased and target P3b decreased somewhat with increases in task difficulty. The findings suggest that increased perceptual discrimination difficulty between the target and standard stimuli increases P3a amplitude. Theoretical implications are discussed.

Keywords: P3a; P3b; P300; Oddball; Visual stimuli; Distracter; Task difficulty

1. Introduction

The P300 event-related brain potential (ERP) is often obtained using an oddball paradigm wherein the participant responds either covertly or overtly to one of two different stimuli that are randomly presented, with one occurring less frequently than the other. In the three-stimulus oddball, an infrequent nontarget called a “distracter” is randomly inserted into the stimulus series. When perceptually novel (e.g., dog barks, color forms, etc.) distracters occur in a series of typical stimuli (e.g., tones, letters of the alphabet, etc.), a “novelty P300” is produced that exhibits a frontal/central maximum amplitude distribution, a short peak latency, and habituates relatively rapidly (Courchesne et al., 1975, 1978; Knight, 1984). In addition, an infrequent tone in the absence of a task can produce a positive potential with a central/parietal amplitude distribution and short latency, which has been dubbed the “P3a” to distinguish it from the task-relevant target “P3b” potential (Snyder and Hillyard, 1976; Squires et al., 1975). Several studies have demonstrated that the novelty P300 is the same potential as the P3a for both auditory and visual stimuli (Demiralp et al., 2001; Simons et al., 2001; Spencer et al., 1999).

These results imply that stimulus and task attributes governing redirected attentional focus contribute to P3a and P3b generation (Hartikainen and Knight, 2003; Knight, 1997; Polich, 2003). However, a key factor in eliciting the P3a with non-novel stimuli is the target/standard task discrimination difficulty. Katayama and Polich (1998) employed an auditory three-stimulus paradigm and manipulated the perceptual target/standard discrimination task difficulty. When the discrimination was easy (2000/1000 Hz) and the distracter stimulus discrepant (500 Hz), P300 amplitude was similar for the target and nontarget stimuli and largest over the parietal locations. When the discrimination was difficult (2000/1940 Hz) and the distracter proportionately distinct (970 Hz), P300 components that were largest over the central locations for the distracter compared to the parietal maximum target measures—similar to the P3a. This report was the first to indicate that P3a could be readily elicited by a non-novel or “typical” stimulus distracter when the attentional mechanisms are strongly activated in the context of hard target/standard discrimination.

Comerchero and Polich (1998, 1999) evaluated auditory and visual distracter stimuli across task difficulty levels and found

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that for both modalities non-novel distracters in the context of a hard discrimination task produced a central maximum P3a potential, with the strongest effects obtained for the most discrepant, high stimulus distracter salience conditions. Additional studies have substantiated the role of task difficulty for P3a generation, as high discrimination difficulty between the target and standard stimuli appears to engage frontal attentional mechanisms more strongly so that distracter disruption of the processing produces large frontal/central P3a components (Demiralp et al., 2001; Polich and Comerchero, 2003). Thus, stimulus context can produce different P300 waveforms, since distracter salience and task discrimination difficulty determine amplitude topography (cf. Jeon and Polich, 2001; Katayama and Polich, 1996; Nittono and Ullsperger, 2000; Polich and Kok, 1995; Suwazono et al., 2000).

1.1. Present study

The major goal of the present study was to characterize how target/standard discrimination task difficulty affects P3a production from a salient non-novel distracter stimulus. The size of the visual task-relevant stimuli was systematically manipulated to increase error rates and response time across task conditions. Stimulus sizes were developed based on pilot work, such that the "medium" difficulty level would produce about a 10–15% error rate as has been employed in previous studies. If P3a is directly related to task difficulty, behavioral increases in the perceptual discrimination should be associated with increases in P3a amplitude up to some empirically defined maximum.

2. Method

2.1. Participants

A total of 15 (11F, 4M) undergraduate students between the ages of 19–27 were assessed (M=20.9, SD=2.3 years). All individuals reported being free of neurological/psychiatric disorders, provided informed written consent, and received a cash payment or course credit for their participation.

2.2. Procedure

Visual stimuli were presented once every 2 s for 100 ms duration on a gray background of a computer monitor placed 80 cm in front of the participant. The target stimulus (0.12) was a blue circle 3.5 cm in diameter, and the distracter stimulus (0.12) was an 18 cm^2 square with a black/white checkerboard pattern (1 cm checks). Discrimination task difficulty was manipulated by using blue circle standard stimuli (0.76), which varied in diameter: 2.7, 3.0, or 3.3 cm for the easy, medium, and hard tasks, respectively. The diameter length of the standard stimuli was based on previous studies and designed to affect task performance error rate and response time. A total of 250 stimuli occurred in each condition, with randomized stimulus presentation and condition order counterbalanced. Participants were instructed to respond to the target by pressing a mouse key as quickly as possible and to refrain from responding to all other stimuli. Only correct responses to target trials were included in the average.

2.3. Electrophysiological recordings

Electroencephalographic (EEG) activity was recorded with an electrode cap from 19 electrode sites, Fz, Cz, Pz, FP1/2, F3/4, F7/8, C3/4, T7/8, P3/4, P7/8, O1/2, referenced to linked earlobes, with a forehead ground and impedance at 10 kΩ or less. Additional bipolar electrodes were placed at the outer left and right canthi and above and below the left eye to measure ocular (EOG) activity. The band pass was 0.01–100 Hz (6 dB octave/slope), and the signals were digitized at 256 Hz for 1024 ms, with a 50 ms prestimulus baseline. Waveforms were averaged off-line, and trials on which the EEG or EOG exceeded ±100 μV rejected. Single-trial data were also subjected to an EOG correction procedure to remove any remaining artifact (Semlitsch et al., 1986). All analyses of variance were repeated measures, with Geisser–Greenhouse corrections applied as needed and the corrected probability values reported. Newman–Keuls means comparisons were used for post-hoc comparisons, with the appropriate error term used for assessing main effects or interactions.

3. Results

3.1. Task performance

A one-factor (3 task difficulty levels) repeated measures analysis of variance was performed on the error rate and response time (RT) from the target stimuli. Error rate for target detection was defined as the proportion of missed targets and increased (4.2%, 11.3%, 36.4%) across the easy, medium, and hard tasks, $F(2,28)=45.8$, $p<0.0001$, with virtually no false alarms made. Post-hoc comparisons found that the easy task produced marginally fewer errors than the medium task ($p<.06$). Both the easy and medium tasks demonstrated significantly fewer errors than the hard task ($p<.001$, both cases). RT increased (530, 565, 627 ms) across the easy, medium, and hard tasks, $F(2,28)=11.6$, $p<0.001$. Post-hoc comparisons found that the easy task produced marginally shorter RT than the medium task ($p<.10$). Both the easy and medium task demonstrated significantly shorter RT than the hard task ($p<.006$, both cases). The task difficulty manipulation was therefore confirmed by the error rate and RT results.

3.2. ERP analysis

The mean number of distracter stimulus trials in each waveform decreased slightly as task difficulty increased (19.5, 19.5, 16.7 trials), but no reliable differences among conditions was obtained ($F(2,28)=2.1$, $p>.10$). The mean number of target stimulus trials in each waveform decreased as task difficulty increased (22.3, 19.7, 14.5 trials), with a significant difference among conditions obtained ($F(2,28)=15.0$, $p<.001$). Additional correlational analyses indicated that