

## P3a and P3b from typical auditory and visual stimuli

Marco D. Comerchero<sup>a</sup>, John Polich<sup>b,\*</sup>

<sup>a</sup>Department of Psychology, University of California, San Diego, La Jolla, CA 92037, USA

<sup>b</sup>Department of Neuropsychology, The Scripps Research Institute, 10550 North Torrey Pines Road, La Jolla, CA 92037, USA; accepted for publication: 28 April 1998

### Abstract

**Objective:** Target/standard discrimination difficulty was manipulated systematically to assess how this variable affects target and nontarget P300 scalp distributions for both auditory and visual stimuli.

**Design and methods:** A 3-stimulus paradigm (target, standard, nontarget) was employed in which subjects ( $n = 16$ ) responded only to an infrequently occurring target stimulus. The perceptual discrimination difficulty between the target and more frequently occurring standard stimuli was varied as Easy or Difficult in different conditions, while holding the nontarget stimulus properties constant.

**Results:** When target/standard discrimination was Easy, P300 amplitude was larger for the target than the nontarget across all electrode sites, and both demonstrated parietal maximums. In contrast, when target/standard discrimination was Difficult, target amplitude (P3b) was larger parietally and occurred later than nontarget components, whereas nontarget amplitude (P3a) was larger and earlier than the target P300 over the frontal electrode sites. Similar outcomes across task conditions were obtained for both auditory and visual stimuli.

**Conclusions:** The findings suggest that target/standard discrimination difficulty, rather than stimulus novelty, determines P3a generation for both auditory and visual stimulus modalities. © 1999 Elsevier Science Ireland Ltd. All rights reserved

**Keywords:** P300; P3a; P3b; Event-related potential (ERP); Auditory/visual stimuli; Three-stimulus paradigm; Stimulus context

### 1. Introduction

In many event-related brain potential (ERP) studies, the P300 component is obtained with the so-called ‘oddball’ paradigm, wherein two stimuli are presented with different probabilities in a random order. The subject is required to discriminate the infrequent target stimulus from the frequent standard stimulus by noting the occurrence of the target, typically by pressing a button or mentally counting. The P300 elicited by the target stimulus in this task is a large, positive-going potential that is of maximum amplitude over the parietal electrode sites with a peak latency of about 300–350 ms for auditory and 350–450 ms for visual stimuli in normal young adults (Johnson, 1988; Picton, 1992). This brain potential is thought to reflect attentional resource allocation when working memory is engaged and despite its simplicity, has provided a great deal of infor-

mation about the neural activity underlying fundamental cognitive operations (Donchin and Coles, 1988; Polich, 1998).

#### 1.1. P3a vs. P3b

The ‘3-stimulus’ paradigm is a modification of the oddball task in which infrequent-nontarget stimuli are inserted into the sequence of target and standard stimuli. When ‘novel’ stimuli (e.g. dog barks, color forms, etc.) are presented as infrequent nontarget stimuli in the series of more ‘typical’ target and standard stimuli (e.g. tones, letters of the alphabet, etc.), a P300 component that is large over the frontal/central areas is produced with auditory, visual, and somatosensory stimuli (Courchesne et al., 1984; Knight, 1984; Yamaguchi and Knight, 1991). This ‘novelty’ P300 is sometimes called the ‘P3a,’ whereas the parietal maximum P300 from the target stimulus is sometimes called the ‘P3b’ (Courchesne et al., 1975; Squires et al., 1975). Because the P3a exhibits an anterior/central scalp distribution, a relatively short peak latency, and habituates

\* Corresponding author. Tel.: +1 619 7848176; fax: +1 619 7849293; e-mail: polich@scripps.edu

rapidly, it has been interpreted as reflecting frontal lobe function (Friedman et al., 1993; Friedman and Simpson, 1994; Knight, 1996).

In another variant of the 3-stimulus paradigm, infrequent-nontarget ‘typical’ visual stimuli that are easily recognized (i.e. not novel) have been found to elicit a P300 with maximum amplitude over the central/parietal rather than frontal/central areas (Courchesne, 1978; Courchesne et al., 1978). This component is sometimes referred to as a ‘no-go’ P300, because subjects do not respond to the infrequent nontarget. Infrequent nontarget auditory tone stimuli (i.e. not novel) inserted into the traditional oddball sequence will elicit a parietal maximum P300 that is smaller and later than the target P300 (Pfefferbaum et al., 1980; Pfefferbaum and Ford, 1988). Thus, for both the visual and auditory modalities, the novel stimuli elicit a central maximum P300 whereas infrequent nontarget stimuli elicit a central/parietal P300 (cf. Grillon et al., 1990; Verbaten et al., 1997).

### 1.2. Stimulus context

Although distinguishing among the various P300 potentials is of theoretical and empirical importance, systematic assessments of the 3-stimulus paradigm are few. Katayama and Polich (1996b) manipulated target and nontarget stimulus probability in an auditory 3-stimulus paradigm and obtained highly consistent results for both target and nontarget stimuli: P300 components from the nontarget tones were essentially the same as those from target stimuli, and P300 target stimulus measures were unaffected by the probabilities of either the standard or nontarget stimuli. A second study compared target stimulus P300 from 3-, 2-, and single-stimulus auditory paradigms and found similar components across tasks (cf. Katayama and Polich, 1996a; Polich and Heine, 1996; Mertens and Polich, 1997). These findings indicate that P300 components from target and nontarget stimuli are both affected by stimulus probability variation even though only the target stimulus requires a response.

Katayama and Polich (1998) assessed the role of task difficulty to examine more closely the effects of stimulus context on P300 component scalp distribution. In this study, the perceptual distinctiveness between the target and standard stimuli was manipulated in an auditory 3-stimulus task by using typical tone stimuli that varied in pitch. When the target/standard discrimination was easy and the nontarget/standard difference was large, P300 target amplitude was larger than nontarget amplitude across the midline electrode sites, and both component types were largest over the parietal sites. However, when target/standard discrimination was difficult and the nontarget/standard difference was large, the nontarget stimulus elicited a P300 that was greater in amplitude frontally and shorter in latency than the target P300, findings remarkably similar to those previously reported when ‘novel’ nontarget stimuli have been employed (Courchesne et al., 1975, 1978; Courchesne, 1978;

Friedman et al., 1993).

Taken together, these results imply that when the perceptual discrimination between the target and standard stimulus is difficult, increased frontal/central amplitude for the infrequent nontarget P300 (P3a) and a parietal maximum for the target P300 (P3b) are obtained. Theoretically, this outcome suggests that the P3a vs. P3b distinction emerges because the stimulus context defines the degree of attentional focus required for the primary discrimination task, which is interrupted by an infrequently occurring nontarget stimulus event. When considered with the P3a/P3b findings reviewed above, it is reasonable to suppose that stimulus context – the relative perceptual distinctiveness among stimuli – affects both target and nontarget P300 amplitude because these components are generated by different neural structures. Indeed, correlations between magnetic resonance imaging (MRI) gray matter volume measurements and P300 amplitude demonstrate distinct regional differences: frontal areas produce stronger associations with nontarget startling stimuli, and parietal areas produce stronger associations with target stimuli (Ford et al., 1994). Additional ERP and MRI findings also indicate frontal lobe activity for the detection of rare but alerting stimuli (Knight, 1996, 1997; Potts et al., 1996; McCarthy et al., 1997; Polich et al., 1997; Verbaten et al., 1997). Thus, P300 amplitude from different stimulus contexts appears to reflect brain areas that are related to specific stimulus evaluation processes.

### 1.3. Present study

If stimulus context determines P3a/P3b generation in the manner outlined above, then the nontarget P300 should be affected by the magnitude of the target/standard perceptual difference for the auditory and visual modalities as has been found for novel and no-go paradigms: Easy target/standard discrimination should produce parietal maximum P300 distributions, whereas difficult target/standard discrimination should produce greater frontal P300 amplitude (Friedman and Simpson, 1994; Verbaten et al., 1997; Katayama and Polich, 1998). In this view, the nature of the stimulus context will direct attentional focus such that an infrequent nontarget stimulus will interrupt the processing operations employed in a difficult target/stimulus discrimination and engage frontal lobe activity much more forcefully compared to a relatively easy discrimination task.

## 2. Subjects and methods

### 2.1. Subjects

A total of 16 young adults (8 male, 8 female) served as subjects (mean age 21.4, SD 1.4 years) and received course credit or pecuniary remuneration for their participation. All subjects reported being free of neurological and psychiatric disorders and provided written, informed consent.

## 2.2. Recording conditions







Electroencephalographic (EEG) activity was recorded at the Fz, Cz, and Pz electrode sites, referred to linked earlobes, with a forehead ground and impedance at 10 k $\Omega$  or less. Additional electrodes were placed at the outer left canthus and below the left eye to measure EOG activity with a bipolar recording. The bandpass was 0.01–30 Hz (6 dB octave/slope), and the EEG was digitized at 4.0 ms per point for 1024 ms, with a 100 ms prestimulus baseline. Waveforms were averaged off-line, such that trials on which the EEG or EOG exceeded  $\pm 90 \mu\text{V}$  were rejected automatically. Further, single-trial data were subjected to an EOG correction procedure to remove any remaining artifact (Semlitsch et al., 1986). All experimental conditions were recorded with eyes open, and rest periods were provided between conditions as well as half way through each recording block.

## 2.3. Procedure

Table 1 summarizes the stimulus properties for the auditory and visual modalities. EEG activity was recorded during 4 blocks (two auditory, two visual), each of which consisted of 350 stimulus presentations that lasted approximately 12 min. Stimuli were defined as target, nontarget, and standard and presented with probabilities of 0.10, 0.10, and 0.80, respectively. Task conditions were defined according to the level of perceptual difficulty of the target/standard discrimination, such that for each modality subjects were presented with one Easy and one Difficult condition. The task in all conditions was to respond to the target stimulus by pushing a mouse button with the right index finger as quickly and accurately as possible. Response time and error rates were recorded. All subjects were given a practice block consisting of 15 stimulus trials before each condition. Modality order was counterbalanced across subjects, but the Easy task was always presented first for each modality to promote successful task performance in the subsequent Difficult condition.

Table 1

Stimulus characteristics for each type, task condition (Easy or Difficult target/standard discrimination), and modality (auditory = pitch, visual = area – shape<sup>a</sup>)

Target/standard discrimination	Modality			
	Auditory (Hz)		Visual (cm <sup>2</sup> )	
	Easy	Difficult	Easy	Difficult
Target (0.10)	2000	2000	12.57 	12.57 
Standard (0.80)	1000	1940	6.16 	10.18 
Non-target (0.10)	500	500	12.57 	12.57 

<sup>a</sup>The shape sizes are relative and are presented for illustrative purposes; the actual stimulus sizes were those indicated by the areas.

## 2.4. Stimuli

Auditory tones were presented binaurally in a random series at 75 dB SPL through headphones once every 2 s, with 50 ms plateau and 10 ms rise/fall times. Visual stimuli were solid blue shapes presented on a computer monitor in a random series 1.5 m in front of the subject at a medium intensity level once every 2 s, with a duration of 75 ms. The auditory conditions were similar to those used previously, whereas the visual stimulus conditions were developed with pilot testing and designed to mimic the critical parameters of the auditory study (cf. Katayama and Polich, 1998).

## 2.5. Data analyses

The P300 component was defined as the largest positive-going peak occurring within a specific latency window defined by the task conditions, with auditory = 250–450 ms and visual = 350–600 ms. Peak amplitude was measured relative to the prestimulus baseline, and peak latency was measured from the time of stimulus onset. Because the primary purpose was to assess the P300 across the varying stimulus conditions, the other ERP components will not be discussed.

## 3. Results

### 3.1. Task performance

Table 2 summarizes the performance data from all task conditions. A two-factor (2 modalities  $\times$  2 difficulty levels) multivariate analysis of variance (MANOVA) was performed on the response time (RT) from the target stimuli. RT for the Easy tasks was significantly shorter than for the Difficult tasks,  $F(1,15) = 57.6$ ,  $P < 0.001$ . Target hit rate was significantly higher in the Easy tasks than in the Difficult tasks,  $F(1,15) = 31.6$ ,  $P < 0.001$ . No interactions were obtained for either analysis. The false positive rates were

Table 2

Mean response time (ms) and performance rates for each task condition (Easy or Difficult target/standard discrimination)

	Auditory modality		Visual modality	
	Easy	Difficult	Easy	Difficult
Response time (ms)	462	597	474	557
Target hits (%)	99.6	87.5	99.3	82.9
False positives (%)				
Standard	0.09	2.19	0.07	1.61
Nontarget	0.89	0.18	0.71	0.00

also assessed, with the Easy task yielding fewer false positives than the Difficult task, for both standards  $F(1,15) = 10.9$ ,  $P < 0.005$ , and nontargets,  $F(1,15) = 6.0$ ,  $P < 0.05$ . Thus, the behavioral data demonstrated that the task difficulty manipulation was successful.

### 3.2. ERP analysis

Fig. 1 presents the grand average ERPs from the target, standard, and nontarget auditory and visual stimuli in the Easy and Difficult task conditions. For the Easy tasks, target stimuli elicited P300 components that were largest at the parietal electrode. Nontarget stimuli elicited P300 components that were similar in morphology to those elicited by target stimuli but with appreciably smaller amplitude across all electrode sites. For the Difficult tasks, target stimuli elicited P300 components that exhibited smaller amplitudes and longer latencies than those from the Easy tasks. Nontarget stimuli elicited P300 components that were larger and

earlier at the frontal and central electrodes than those from the target stimuli. Target P300 amplitude was larger than the nontarget amplitude at the parietal electrode.

#### 3.2.1. P300 amplitude

Fig. 2 illustrates the mean P300 amplitudes from the target and nontarget stimuli for each experimental condition as a function of electrode site. The amplitude data were assessed with a 4-factor (2 Modalities  $\times$  2 Difficulty levels  $\times$  2 Stimulus types  $\times$  3 Electrodes) MANOVA. Table 3 summarizes the results of this analysis. Main effects of modality, stimulus, and electrode were obtained ( $P < 0.02$ , in all cases). P300 parietal maximum amplitude was larger for the target than the nontarget stimuli to yield a significant  $S \times E$  interaction. Further, target stimulus P300 amplitude was larger in the Easy task but nontarget P300 amplitude was larger in the Difficult task, with visual stimuli eliciting larger components overall than auditory stimuli to produce significant  $D \times S$  and  $M \times D \times S$  interactions. These amplitude effects suggest that the nontarget stimulus contexts caused the P300 outcomes, such that clear P3a and P3b components were observed in both modalities even though typical (not novel) stimuli were employed.

#### 3.2.2. Vector analysis

To assess scalp distribution differences among conditions, P300 amplitude data from the target and nontarget stimuli were re-analyzed after the data were normalized by vector length (McCarthy and Wood, 1985): Each subject's amplitude value was divided by the square root of the sum of the squared amplitudes over the 3 midline electrode

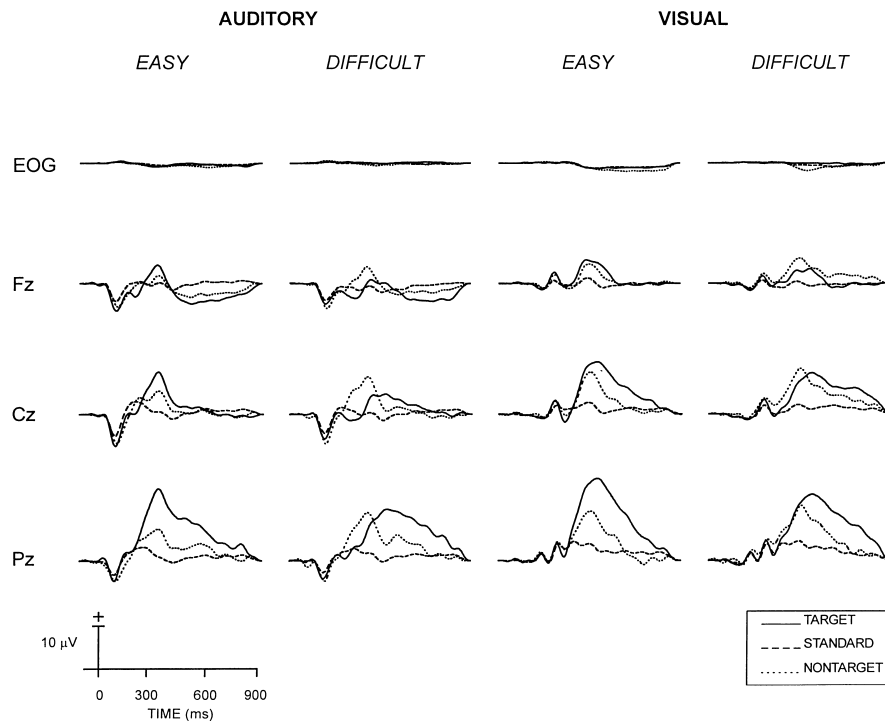


Fig. 1. Grand averaged ERPs from auditory and visual modalities for each task difficulty, stimulus type, and recording site ( $n = 16$ ).

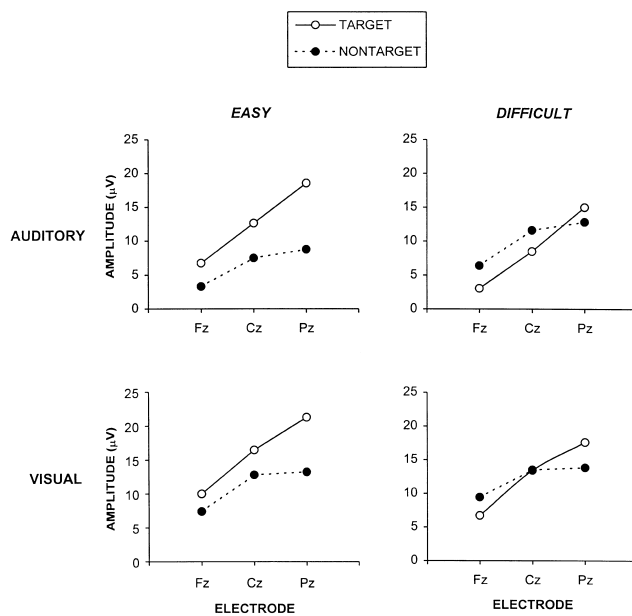


Fig. 2. Mean P300 amplitude from the target and nontarget stimuli for each modality from each task difficulty condition as a function of midline electrode site.

locations for each stimulus in each condition (i.e. the vector length for each condition). This transformation normalized the modality, difficulty, and stimulus type effects to permit statistical evaluation of component scalp distribution (Johnson, 1993).

The transformed data were analyzed with the same 4-factor analysis employed previously and the results are summarized in the middle column of Table 3. The main effect of electrode and the  $S \times E$  interaction remained significant, with the  $M \times S$ , the  $D \times S$ , and the  $M \times D \times S$  interactions eliminated. More important, for the Easy task P300 did not differ between target and nontarget stimuli across electrode

sites, but for the Difficult task nontarget P300 was larger at the Fz and Cz electrodes whereas target P300 was larger at the Pz electrode to yield a reliably significant  $D \times S \times E$  interaction. Hence, the scalp topography patterns for each task condition and stimulus type suggest that the P3a and P3b neural generators were differentially engaged as a function of stimulus context demands. Finally, P300 was larger for visual compared to auditory stimuli at the Fz and Cz electrodes, but larger for auditory compared to visual stimuli for the Pz to Cz difference to yield a significant  $M \times E$  interaction. Thus, normalization of the P300 amplitude data also demonstrated the effects of stimulus context.

### 3.2.3. P300 latency

Fig. 3 illustrates the mean P300 latencies for each experimental condition and electrode site. An analysis similar to that performed on the amplitudes was performed on the latency data, with the outcomes summarized in the right-most column of Table 3. All of the main effects from this MANOVA apparent in Fig. 3 were significant ( $P < 0.001$  in all cases). For auditory stimuli, target latency in the Easy task was shorter than in the Difficult task, whereas there was no difference between task difficulty levels for nontargets; P300 components from the visual stimuli displayed this same outcome but with longer overall latencies to yield a significant  $M \times D \times S$  interaction ( $P < 0.05$ ). The significant  $M \times D \times E$  interaction ( $P < 0.002$ ) originated primarily from modality differences. For the auditory modality, Easy task stimuli produced shorter latencies than Difficult task stimuli from the Cz and Pz electrodes but not Fz. For the visual modality, Easy task stimuli produced shorter latencies than Difficult task stimuli at Fz only. The  $M \times D \times S \times E$  interaction was significant primarily because of a greater difference between target and nontarget latencies in the Easy compared to Difficult task across elec-

Table 3

Summary of the 4-factor multivariate analyses of variance (2 Modalities  $\times$  2 Difficulty levels  $\times$  2 Stimulus types  $\times$  3 Electrodes) performed on the P300 amplitude, vector transformation, and peak latency data

Source (df)	Amplitude ( $\mu V$ )		Vector		Latency (ms)	
	F	P	F	P	F	P
Modality (1,15)	9.2	0.01	—	—	104.2	0.0001
Difficulty (1,15)	—	—	—	—	28.6	0.0001
Stimulus (1,15)	7.1	0.02	—	—	56.8	0.0001
Electrode (2,30)	53.3	0.0001	50.2	0.0001	13.2	0.0001
$M \times D$ (1,15)	—	—	—	—	—	—
$M \times S$ (1,15)	—	—	—	—	—	—
$D \times S$ (1,15)	68.4	0.0001	—	—	108.9	0.0001
$M \times E$ (2,30)	—	—	5.3	0.02	—	—
$D \times E$ (2,30)	—	—	—	—	—	—
$S \times E$ (2,30)	31.4	0.0001	13.4	0.0001	—	—
$M \times D \times S$ (1,15)	6.7	0.05	—	—	6.3	0.05
$M \times D \times E$ (2,30)	—	—	—	—	8.0	0.002
$M \times S \times E$ (2,30)	—	—	—	—	—	—
$D \times S \times E$ (2,30)	—	—	8.2	0.002	—	—
$M \times D \times S \times E$ (2,30)	—	—	—	—	3.4	0.05

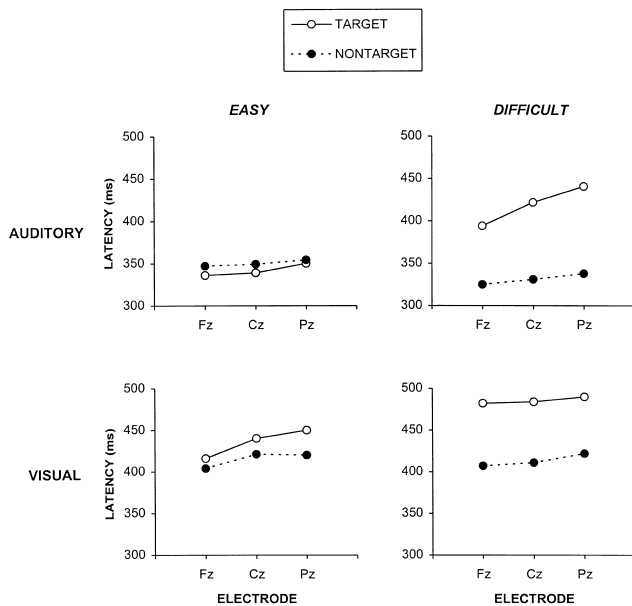


Fig. 3. Mean P300 latency from the target and nontarget stimuli for each modality from each task difficulty condition as a function of midline electrode site.

trode positions ( $P < 0.05$ ). In sum, target and nontarget stimuli in the Easy task exhibited no latency differences, whereas target latencies were longer than nontarget latencies in the Difficult task.

#### 4. Discussion

Response time and hit rate results confirmed the successful manipulation of task difficulty by varying the degree of perceptual discrimination between target and standard stimuli. When the target was physically similar to the standard, reaction time increased and hit rate decreased compared to when the target was very different from the standard. Although these task difficulty effects were somewhat stronger for the auditory compared to visual stimulus conditions for RT, the ERP outcomes were comparable for both modalities. Thus, small target/standard differences demand more stimulus processing compared with large target/standard differences.

##### 4.1. Target vs. nontarget P300

The target stimulus in each task condition of the 3-stimulus paradigm elicited a P300 component that was largest over the parietal electrode site. The target P300 also was affected by target/standard discrimination difficulty: When the target was very similar to the standard, P300 (P3b) amplitude decreased and latency lengthened a result highly consistent with many reports using a classic oddball paradigm (Polich, 1986, 1987; Johnson, 1988; Verleger, 1997). For the Easy conditions the nontarget stimulus elicited a

smaller P300 than the target stimulus and demonstrated a similar parietal maximal amplitude distribution; nontarget latency was shorter overall than target latency. These results are in close agreement with previous 3-stimulus paradigm studies (Pfefferbaum et al., 1980; Grillon et al., 1990; Katayama and Polich, 1996a,b). For the Difficult condition, however, nontarget amplitude was larger than target amplitude over the frontal/central electrodes; nontarget latency was much shorter than target latency for both modality conditions (Katayama and Polich, 1998). Taken together, these results indicate that the stimulus context facilitated nontarget processing in the Difficult compared to Easy task.

##### 4.2. P3a revisited

The nontarget stimuli in the Difficult condition of each modality elicited a frontal P300, which closely resembles the P3a from 'novel' stimulus paradigms as well as that obtained by Katayama and Polich (1998) from typical auditory stimuli. Hence, manipulation of target/standard stimulus discriminability produced a stimulus environment for the Difficult condition in which the infrequently occurring nontarget engaged focal attention in a manner similar to that observed previously for 'novel' stimuli (Courchesne et al., 1975; Courchesne, 1978; Friedman and Simpson, 1994; Knight, 1996). Because all stimuli of the present study were purposefully 'typical' in structure, these results imply that an anterior P3a component can be produced without using 'novel' stimuli. If stimulus context is defined primarily by a difficult target/standard discrimination, attentional redirection to the nontarget could occur by means of the frontal lobe activation that may govern P3a (cf. Potts et al., 1996; McCarthy et al., 1997; Polich et al., 1997). A relatively easy target/standard discrimination, however, would mitigate this outcome because the stimulus context would not demand intense attentional focus, thereby facilitating more automatic nontarget processing (Katayama and Polich, 1996a,b, 1998; Verbaten et al., 1997).

Although the neural loci for both P3a and P3b generation are not yet completely clear (cf. Knight, 1990, 1996, 1997; Polich and Squires, 1993; Halgren et al., 1995a,b), if the neuroelectric events that underlie P300 generation are related to an interaction between frontal lobe and hippocampal/temporal-parietal function as has been suggested (Ford et al., 1994; Knight, 1996; Polich et al., 1997), then it is reasonable to suppose that task condition manipulations such as those employed in the present study can be used to assess this possibility directly. Thus, the 3-stimulus paradigm appears to produce a rich set of experimental possibilities for delineating the neural operations engaged when a well-defined target/standard perceptual context is confronted by an infrequent but 'typical' stimulus event.

## Acknowledgements

This study was supported by an Undergraduate Research Scholarship to the first author from the Committee on Undergraduate Scholarships and Honors, University of California, San Diego, and NIDA Grant DA08363 to J.P. We thank Dr. Aaron Ilan for his helpful comments with earlier versions of this paper. This is manuscript NP11058 from The Scripps Research Institute.

## References

- Courchesne, E. Changes in P3 waves with event repetition: Long-term effects on scalp distribution and amplitude. *Electroenceph. clin. Neurophysiol.*, 1978, 45: 754–766.
- Courchesne, E., Hillyard, S.A. and Galambos, R. Stimulus novelty, task relevance and the visual evoked potential in man. *Electroenceph. clin. Neurophysiol.*, 1975, 39: 131–143.
- Courchesne, E., Courchesne, R.Y. and Hillyard, S.A. The effect of stimulus deviation on P3 waves to easily recognized stimuli. *Neuropsychologia*, 1978, 16: 189–199.
- Courchesne, E., Kilman, B.A., Galambos, R. and Lincoln, A. Autism: Processing of novel auditory information assessed by event-related brain potentials. *Electroenceph. clin. Neurophysiol.*, 1984, 59: 238–248.
- Donchin, E. and Coles, M.G.H. Is the P300 component a manifestation of context updating?. *Behav. Brain Sci.*, 1988, 11: 357–374.
- Ford, J.M., Sullivan, E.V., Marsh, L., White, P.M., Lim, K.O. and Pfefferbaum, A. The relationship between P300 amplitude and regional gray matter volumes depends upon the attentional system engaged. *Electroenceph. clin. Neurophysiol.*, 1994, 90: 228.
- Friedman, D. and Simpson, G.V. ERP amplitude and scalp distribution to target and novel events: Effects of temporal order in young, middle-aged and older adults. *Cogn. Brain Res.*, 1994, 2: 49–63.
- Friedman, D., Simpson, G. and Hamberger, M. Age related changes in scalp topography to rare and target stimuli. *Psychophysiology*, 1993, 30: 383–396.
- Grillon, C., Courchesne, E., Ameli, R., Elmasian, R. and Braff, D. Effects of rare non-target stimuli on brain electrophysiological activity and performance. *Int. J. Psychophysiol.*, 1990, 9: 257–267.
- Halgren, E., Baudena, P., Clarke, J., Heit, G., Li :égeois, Chauvel, P. and Musolino, A. Intracerebral potentials to rare target and distractor auditory and visual stimuli. I. Superior temporal plane and parietal lobe. *Electroenceph. clin. Neurophysiol.*, 1995a, 94: 191–220.
- Halgren, E., Baudena, P., Clarke, J., Heit, G., Marinkovic, K., Devaux, B., Vignal, J.-P. and Biraben, A. Intracerebral potentials to rare target and distractor auditory and visual stimuli. II. Medial, lateral and posterior temporal lobe. *Electroenceph. clin. Neurophysiol.*, 1995b, 94: 229–250.
- Johnson, R. The amplitude of the P300 component of the event-related potential: Review and synthesis. In: P. Ackles, J.R. Jennings and M.G.H. Coles (Eds.), *Advances in Psychophysiology: A Research Annual*, Vol. 3. JAI Press, Greenwich, CT, 1988, pp. 69–138.
- Johnson, R. On the neural generators of the P300 component of the event-related potential. *Psychophysiology*, 1993, 30: 90–97.
- Katayama, J. and Polich, J. P300 from one-, two-, and three-stimulus auditory paradigms. *Int. J. Psychophysiol.*, 1996a, 23: 33–40.
- Katayama, J. and Polich, J. P300, probability, and the three-tone paradigm. *Electroenceph. clin. Neurophysiol.*, 1996b, 100: 555–562.
- Katayama, J. and Polich, J. Stimulus context determines P3a and P3b. *Psychophysiology*, 1998, 35: 23–33.
- Knight, R.T. Decreased response to novel stimuli after prefrontal lesions in man. *Electroenceph. clin. Neurophysiol.*, 1984, 59: 9–20.
- Knight, R.T. Neural mechanisms of event-related potentials from human lesion studies. In: J. Rohrbaugh, R. Parasuraman and R. Johnson (Eds.), *Event-related Brain Potentials: Basic Issues and Applications*. Oxford University Press, New York, 1990, pp. 3–18.
- Knight, R.T. Contribution of human hippocampal region to novelty detection. *Nature*, 1996, 383: 256–259.
- Knight, R.T. Distributed cortical network for visual attention. *J. Cogn. Neurosci.*, 1997, 9: 75–91.
- Mertens, R. and Polich, J. P300 from a single-stimulus paradigm: Passive versus active tasks and stimulus modality. *Electroenceph. clin. Neurophysiol.*, 1997, 104: 488–497.
- McCarthy, G., Luby, M., Gore, J. and Goldman-Rakic, P. Infrequent events transiently activate human prefrontal and parietal cortex as measured by functional MRI. *J. Neurophysiol.*, 1997, 77: 1630–1634.
- McCarthy, G. and Wood, C.C. Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroenceph. clin. Neurophysiol.*, 1985, 62: 203–208.
- Pfefferbaum, A. and Ford, J.M. ERPs to stimuli requiring response production and inhibition: Effects of age, probability and visual noise. *Electroenceph. clin. Neurophysiol.*, 1988, 71: 55–63.
- Pfefferbaum, A., Ford, J.M., Roth, W.T. and Kopell, B.S. Age-related changes in auditory event-related potentials. *Electroenceph. clin. Neurophysiol.*, 1980, 49: 266–276.
- Picton, T.W. The P300 wave of the human event-related potential. *J. Clin. Neurophysiol.*, 1992, 9: 456–479.
- Polich, J. Attention, probability, and task demands as determinants of P300 latency from auditory stimuli. *Electroenceph. clin. Neurophysiol.*, 1986, 63: 251–259.
- Polich, J. Task difficulty, probability, and inter-stimulus interval as determinants of P300 from auditory stimuli. *Electroenceph. clin. Neurophysiol.*, 1987, 68: 311–320.
- Polich, J. P300 clinical utility and control of variability. *J. Clin. Neurophysiol.*, 1998, 15: 14–33.
- Polich, J. and Heine, M.R.D. P300 topography and modality effects from a single stimulus paradigm. *Psychophysiology*, 1996, 33: 747–752.
- Polich, J. and Squires, L.R. P300 from amnesic patients with bilateral hippocampal lesions. *Electroenceph. clin. Neurophysiol.*, 1993, 86: 408–417.
- Polich, J., Alexander, J.E., Bauer, L.O., Kuperman, S., Rohrbaugh, J., Morzorati, S., O'Connor, S.J., Porjesz, B. and Begleiter, H. P300 topography of amplitude/latency correlations. *Brain Topogr.*, 1997, 9: 275–282.
- Potts, G.F., Liotti, M., Tucker, D.M. and Posner, M.I. Frontal and inferior temporal cortical activity in visual target detection: Evidence from high spatially sampled event-related potentials. *Brain Topogr.*, 1996, 9: 3–14.
- Semlitsch, H.V., Anderer, P., Schuster, P. and Presslich, O. A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology*, 1986, 23: 695–703.
- Squires, N.K., Squires, K.C. and Hillyard, S.A. Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroenceph. clin. Neurophysiol.*, 1975, 38: 387–401.
- Verbaten, M.N., Huyben, M.A. and Kemner, C. Processing capacity and the frontal P3. *Int. J. Psychophysiol.*, 1997, 25: 237–248.
- Verleger, R. On the utility of P3 latency as an index of mental chronometry. *Psychophysiology*, 1997, 34: 131–156.
- Yamaguchi, S. and Knight, R.T. P300 generation by novel somatosensory stimuli. *Electroenceph. clin. Neurophysiol.*, 1991, 78: 50–55.