Auditory and visual P300 topography from a 3 stimulus paradigm

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Abstract

Objective: The P300 event-related brain potential (ERP) was elicited with auditory and visual stimuli in a separate session of a 3 stimulus oddball paradigm, and the scalp topography was assessed with 15 electrode locations.

Methods: Target (0.10), standard (0.80), and infrequent non-target (0.10) stimuli in the auditory task were 2000, 1000 and 500 Hz tone, and in the visual task, 'X', 'O', and 'H', respectively. The stimuli were presented in a random series, once every 2 s, and participants responded only to the target ($N = 12$).

Results: Target stimuli elicited larger P300 components than non-target did in both stimulus modalities. For both target and non-target stimuli, P300 amplitude was larger and latency longer for the visual compared with the auditory stimulus. Analysis of normalized P300 amplitude data indicated that the target and non-target P300s from both modalities had identical topography.

Conclusion: The findings suggest that both target and non-target stimuli in 3 stimulus oddball paradigm elicited the same type of P300 (P3b) for both stimulus modalities. © 1999 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: P300; Event-related potential; Modality; Three stimulus; Topography

1. Introduction

The P300 component of the event-related brain potential (ERP) reflects fundamental cognitive processes (Donchin and Coles, 1988; Johnson, 1988; Picton, 1992; Polich, 1993) and has been employed in a wide variety of theoretical, empirical and clinical applications (Donchin et al., 1986; Polich, 1998). The P300 often is obtained using the so-called 'oddball' paradigm, wherein two stimuli are presented in a random order, one of which occurs less frequently than the other (i.e. the oddball). The participant is required to discriminate the rare stimulus (target) from the frequent one (standard) by noting the occurrence of the target, typically by pressing a button or mentally counting (e.g. Duncan-Johnson and Donchin, 1977; Polich, 1989; Verleger and Berg, 1991). The P300 elicited by the target in this task is a large, positive-going potential that is largest over the parietal electrode sites and occurs at about 300 ms in normal young adults with auditory stimuli.

1.1. Oddball task variants

There are several modifications of the oddball paradigm. Squires et al. (1975) demonstrated that when the subject was not required to respond actively to the target stimulus in a passive paradigm, P300 had a more anterior/central distribution and shorter latency (P3a) than that from an active discrimination task. Polich et al. (1994) reported that a P300 component could be readily elicited by presenting a single target tone randomly in time as in the oddball paradigm, but with the standard tone replaced by silence. The P300 from the single- or 1 stimulus paradigm yields amplitude and latency topography effects similar to the P300 from the traditional 2 stimulus oddball paradigm (Katayama and Polich, 1996a; Polich and Heine, 1996; Cass and Polich, 1997; Polich and Margala, 1997).

In the 3 stimulus variant of the oddball paradigm, an additional infrequent-non-target stimulus is inserted into the sequence of infrequent target and frequent standard stimuli. Courchesne et al. (1975) reported that colorful, unrecognizable slides (novel stimuli), which were interspersed among the target and standard slides, elicited a fronto-centrally distributed P300 with shorter latency than the component elicited by the target stimulus. This 'novelty' P300 has also been reported for the auditory (Courchesne et al., 1984; Knight, 1984) and somatosensory (Yamaguchi

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and Knight, 1991a,b) stimulus modalities. In addition, easily recognized (i.e. not novel) infrequent non-target slides elicited a centro-parietal rather than fronto-central P300 (Courchesne, 1978; Courchesne et al., 1978). Using an analogous auditory procedure, It was found that an infrequently presented non-target auditory tones inserted into the oddball sequence elicited a parietal P300 that was smaller and later than the target P300 (Pfefferbaum et al., 1980, 1984).

Despite the theoretical and empirical implications of these findings, systematic assessment of major ERP variables on the P300 from the 3 stimulus paradigm have not been readily available. Katayama and Polich (1996a) demonstrated that the target P300 from the 3 tone paradigm was essentially the same as that obtained in two tone or single-tone paradigms. A second study manipulated the probability of target and non-target stimuli in a 3 tone paradigm to assess how this variable affects the P300 from each stimulus category (Katayama and Polich, 1996b). Non-target tone stimuli produced P300 components that were similar to, but generally smaller than those from the target stimuli, with both the target and non-target P300 components similarly affected by the probability of eliciting stimuli (Duncan-Johnson and Donchin, 1977; Polich, 1987). In addition, target P300 amplitude and latency were not affected by the probabilities of either the standard or non-target tone. A third study manipulated the target/standard discrimination difficulty and found that although the target P300 reflected only the target-related variable, non-target P300 was directly affected by the stimulus context as defined by the combination of the target/standard and non-target/standard discrimination ease (Katayama and Polich, 1998). These results have been recently replicated and extended to include both auditory and visual stimuli (Comerchero and Polich, 1998a,b). Taken together, the findings indicate that the 3 stimulus oddball task produces P300s from both the infrequent target and non-target stimuli, with component amplitude similarly determined by probability and task demand variables.

1.2. P300 scalp topography

Early studies of P300 from the two-stimulus oddball task demonstrated no modality effects, although visual P300 is larger in amplitude and longer in latency than auditory P300 (Simson et al., 1977a,b; Squires et al., 1977; Ritter et al., 1979; Picton et al., 1984). This modality independence has been considered as evidence for P300 being an endogenous rather than exogenous ERP component (Donchin et al., 1978). However, subsequent studies have reported modality differences for P300 scalp distribution (Johnson, 1989a,b), which suggest that modality specific neural generators contribute to component generation (Johnson, 1993). More recently, however, a comprehensive study by Naumann et al. (1992) found no modality effects on P300 target stimulus topography in the two-stimulus oddball paradigm across

amplitude normalization techniques and by controlling for Type II error with a large sample size. A similar lack of modality effects on P300 scalp topography has also been reported for in other recent studies (Polich et al., 1996; Polich and Heine, 1996; Ramero and Polich, 1996).

Using a 3 stimulus paradigm, Pfefferbaum et al. (1984) found that infrequent non-target stimuli elicited smaller and later P300 components than target stimuli for both auditory and visual conditions, but only the visual non-target elicited the P300 with central rather than parietal maximum distribution. However, these results are not completely consistent with other findings (Comerchero and Polich, 1998a,b; Katayama and Polich, 1996b; Katayama and Polich, 1998). Thus, the purpose of the present study was to assess stimulus modality effects on the scalp topography for the target and non-target P300s from auditory and visual 3 stimulus paradigms by using comparatively large numbers of electrodes to evaluate topography patterns comprehensively.

2. Method

2.1. Participants

Twelve young adults served as participants (M = 23.1, SD = 3.8 years) and received course credit or payment. Equal numbers of each sex were assessed, and all participants reported being free of neurological or psychiatric disorders.

2.2. Recording conditions

Electroencephalographic (EEG) activity was recorded at the F3/F4, F7/F8, C3/C4, T7/T8, P3/P4, P7/P8, Fz, Cz and Pz electrode sites of the 10–20 system, using an Electro-Cap system, referred to linked earlobes, with a forehead ground and impedance at 10 kΩ or less. Additional electrodes were placed at the outer canthus and below the left eye to monitor EOG activity with a bipolar recording. The filter bandpass was 0.01–30 Hz (6 dB octave/slope). The EEG was digitized at 3.0 ms per point for 768 ms, with a 75 ms prestimulus baseline. Waveforms were averaged off-line, such that trials with a response error or those on which the EEG or EOG exceeded ± 90 μV were rejected automatically. All experimental conditions were recorded with eyes open, and rest periods were provided.

2.3. Procedure

In each experimental condition, 350 stimuli were presented in a random series, once every 2 s, consisting of target, standard and non-target stimuli with probabilities of 0.10, 0.80 and 0.10, respectively. In the auditory condition, ERPs were elicited with 2000 (target), 1000 (standard) and 500 (non-target) Hz tones that were presented binaurally through headphones at 75 dB SPL (50 ms plateau, 10 ms

Table 1
Mean reaction time and performance rates for each modality and stimulus condition

	Auditory		Visual	
	Mean	SD	Mean	SD
Reaction time (ms)	492	125	497	91
Hit targets (%)	98.8	2.0	99.5	1.7
False positive (%)				
Standard	0.03	0.12	0.03	0.12
Non-target	0.73	1.31	0.24	0.84

rise/fall). In the visual condition, ERPs were elicited with a center-field presentation (15 mm in height and 20 mm in width) of 'X' (target), 'O' (standard), and 'H' (non-target) that were viewed from a distance of 130 cm, and lasted for 70 ms. The participants task was to respond to the target by pushing a mouse button with their right index finger as quickly as possible. Each experimental condition lasted about 12 min. The order of the modality conditions was counterbalanced across participants.

2.4. Data analyses

The P300 component was defined as the largest positive-going peak occurring within a specific latency window: For the auditory P300s this was 250–400 ms and for the visual P300s this was 250–500 ms. As the focus of the present study was the modality effects on the target and non-target

Fig. 1. Grand averaged ERPs from auditory (upper) and visual (lower) 3 stimulus paradigm for each stimulus type and recording site (N = 12).

stimuli, only the P300 components from these stimuli will be reported. Peak amplitude was measured relative to the prestimulus baseline, and peak latency was measured from the time of stimulus onset. All analyses of variance (ANOVAs) employed Greenhouse–Geisser corrections to the degrees of freedom when appropriate, and only the corrected probability values are reported. The Tukey method was used for post-hoc comparisons, with a significance level of 0.05.

3. Results

3.1. Behavioral performance

Table 1 summarizes the behavioral data. A one factor analysis (two modalities) found no differences for reaction time or hit rate. A two factor (two modalities × two standard/non-target) analysis of the false positive rate found that non-target elicited more false positives than standard stimuli, $F(1, 11) = 4.9$, $P < 0.05$, although the rate was less than 1% in all cases.

3.2. ERP analyses

Fig. 1 presents the grand average ERPs from the target, standard and non-target stimuli for each modality and electrode. For both modalities, the target stimulus elicited P300 components that were largest over the mid-line and parietal electrodes, and the non-target stimulus also elicited P300 components with smaller amplitudes than those to the target.

3.3. P300 amplitude

Fig. 2 presents the mean P300 peak amplitudes from the target and non-target stimuli for each modality and electrode site. The data were assessed with a 4 factor [two modalities × two stimulus types (target vs. non-target) × 3 anterior-to-posterior × 5 lateral electrodes] analysis of variance. The electrode factors were arranged such that the lateral (coronal) electrode arrays were nested under the anterior-to-posterior factor locations (F7-F3-Fz-F4-F8 vs. T7-C3-Cz-C4-T8 vs. P7-P3-Pz-P4-P8), which yielded two orthogonal electrode factors. This approach permits the direct assessment of interactions between the frontal-to-parietal topography distributions across lateral electrode with respect to the experimental independent variables.

P300 amplitude from auditory stimuli was smaller than that from visual stimuli, $F(1, 11) = 7.8$, $P < 0.02$; target stimuli elicited larger components than non-target stimuli, $F(1, 11) = 25.9$, $P < 0.001$. There were no significant interactions including the modality factor. P300 amplitude was largest over the parietal electrode sites, $F(2, 22) = 11.7$, $P < 0.002$, and over the mid-line, $F(4, 44) = 50.7$, $P < 0.001$. These two factors demonstrated a significant interaction, such that P300 amplitude increased from the
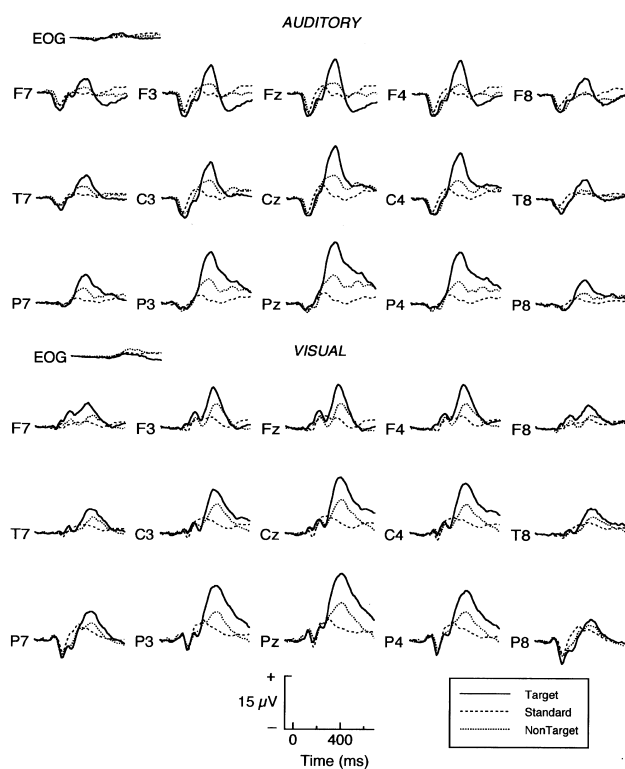
frontal to parietal electrode sites more over the mid-line rather than lateral locations, $F(8, 88) = 12.0$, $P < 0.001$. This pattern was stronger for target P300 amplitude than for non-target P300 to produce a significant 3-way interaction among the stimulus type × anterior/posterior × lateral location factors, $F(8, 88) = 6.7$, $P < 0.001$, and a two-way interaction between stimulus type and lateral location, $F(4, 44) = 16.2$, $P < 0.001$.

3.4. Vector analysis

Scalp distribution effects between the target and non-target stimulus types were assessed further by normalization of the P300 amplitude data from the target and non-target stimuli using a vector length transformation procedure (McCarthy and Wood, 1985): Each amplitude value from each subject was divided by the square root of the sum of squared amplitudes over all the electrode locations for each modality and stimulus type condition (i.e. vector length for each condition). This analysis normalized the effects of modality and stimulus type, so that only the scalp distribution information was compared across task conditions (Johnson, 1993).

Fig. 3 illustrates the transformed data scalp distributions, which were analyzed with the same 4 factor analysis employed previously. No significant interactions among an electrode factor and experimental condition were found, thereby indicating that the P300 scalp topography did not differ by modality or stimulus type.

3.5. P300 latency

Fig. 2 illustrates the mean P300 peak latencies for each experimental condition and electrode site. The same 4 factor analysis was conducted and demonstrated that the auditory
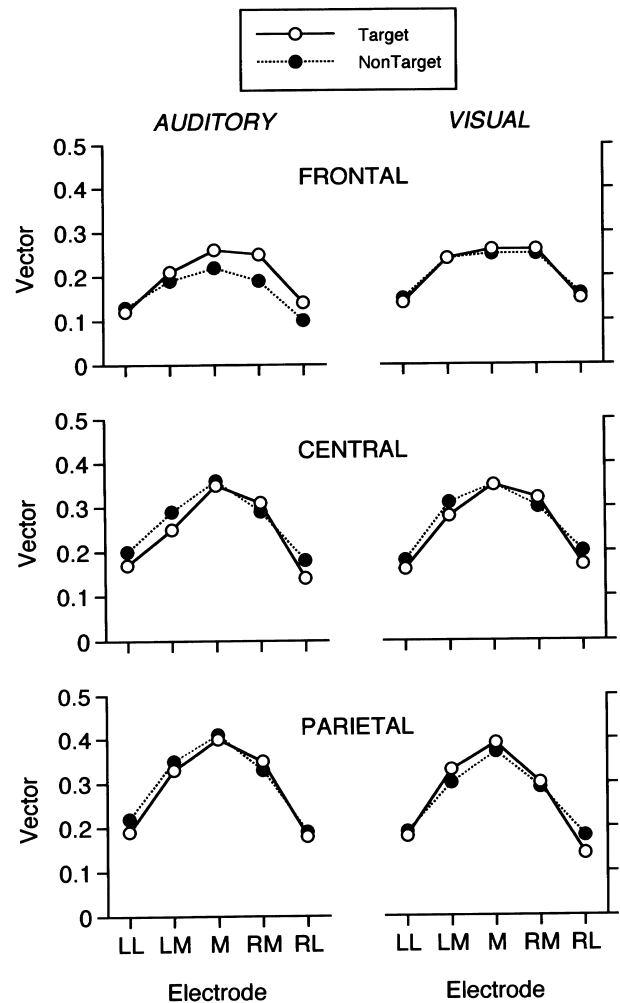
Fig. 3. Mean normalized P300 amplitudes from the target and non-target stimuli in each modality condition as a function of coronal electrode site for the frontal, central and parietal electrode positions (LL, left lateral; LM, left medial; M, mid-line; RM, right medial; RL, right lateral).

stimuli elicited P300 with shorter latency than the visual stimuli, $F(1, 11) = 103.4$, $P < 0.001$. The significant interaction between two electrode factors stemmed from the fact that P300 latency at the lateral was longer than the others at the central electrode locations, whereas lateral peak latency was shorter than the others at the parietal locations, $F(8, 88) = 2.9$, $P < 0.05$. No other effects or interactions were significant.

4. Discussion

4.1. P300 scalp topography

The target stimulus in each modality elicited a P300 component that was largest over the parietal and mid-line electrode sites. The target P300 from the auditory task was smaller in amplitude and shorter in latency than the P300
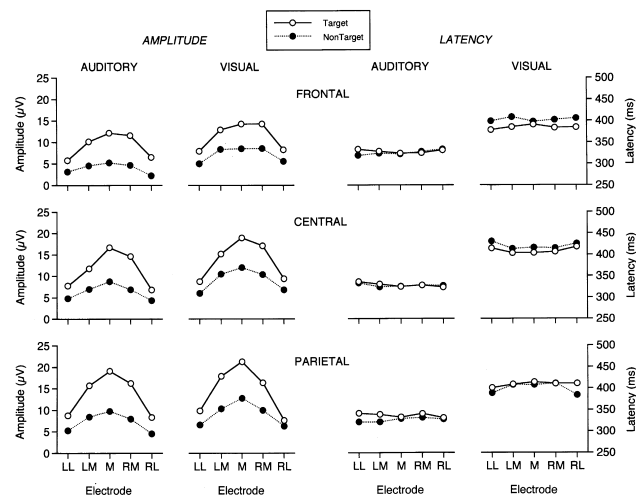
Fig. 2. Mean P300 peak amplitudes and latencies from the target and non-target stimuli in each modality condition as a function of coronal electrode site for the frontal, central and parietal electrode positions (LL, left lateral; LM, left medial; M, mid-line; RM, right medial; RL, right lateral).

from the visual task, which is consistent with the previous reports that comparing auditory and visual P300s using the traditional 2-stimulus oddball task (Naumann et al., 1992; Polich and Heine, 1996; Ramero and Polich, 1996) as well as previous results using a 3 stimulus oddball paradigm (Pfefferbaum et al., 1984). The infrequent non-target stimulus in both modalities also elicited a parietal and mid-line maximum P300. Although the amplitude of the non-target component was smaller than the target P300, non-target P300 latency did not differ from the target P300 for either modality. Pfefferbaum et al. (Pfefferbaum et al., 1980, 1984) found that the non-target P300 was longer in latency than the target P300, but Katayama and Polich (1996b) reported no difference in latency between target and non-target P300s for an auditory 3 stimulus. Katayama and Polich (1998) demonstrated that latencies of the target and non-target P300 from the 3-tone paradigm reflected only the deviation magnitude of the eliciting stimulus from the frequent standard tones (Comerchero and Polich, 1998a,b). Taken together, the present results indicate that the non-target stimulus elicited a P3b component that was highly similar to the P300 from the target stimulus for both auditory and visual stimuli.

In addition, auditory and visual non-target stimuli elicited parietal maximum P300 components. The normalized amplitude analysis indicated that the P300 topography was independent of stimulus modality as well as stimulus type (i.e. target and non-target). Although Pfefferbaum et al. (1984) found that the non-target P300 from visual modality evinced a central rather than parietal maximum scalp distribution, the present study found a parietal maximum P300 for visual non-target stimulus. Comerchero and Polich, 1998a,b; Katayama and Polich (1998) showed that when the target/standard discrimination was difficult, infrequent non-target stimulus elicited P300 with anterior distribution. Thus, the differences between studies may reflect differences in task discrimination ease, as the present findings employed longer inter-stimulus interval, which may make our task relatively easier.

4.2. Conclusion

Given these outcomes, it is reasonable to conclude that the target and non-target stimulus in both the auditory and visual modalities elicited a P3b component with the same neural generator. The findings also indicate the possible applied utility for the 3 stimulus paradigm. As non-target P300 responds to stimulus probability, task variables and has the same scalp topography as that obtained from the oddball task, it could be useful as a non-response probe stimulus that may distinguish automatic processes among various clinical populations. Thus, the P300 from non-target stimuli may be a useful parameter to assess individual cognitive capability in the absence of a response requirement.

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