

BRIEF REPORT

Event-related potentials as an index of similarity between words and pictures

TODD D. WATSON, ALLEN AZIZIAN, STEPHEN BERRY, AND NANCY K. SQUIRES

Department of Psychology, Stony Brook University, Stony Brook, New York, USA

Abstract

This report examines the ERP correlates of processing nontarget stimuli that are conceptually, but not perceptually, similar to a target. In two studies, the P300 component was examined in healthy adults during a multistimulus oddball paradigm. The stimuli were pictures of five objects and their five corresponding names. Participants were required to keep a mental count of number of target presentations. In Experiment 1, the target was the word “globe.” Both the word target and the nontarget picture of the globe elicited large P300s, though the P300 to the picture was smaller in amplitude. No other stimulus elicited a prominent P300. In Experiment 2, the target was the picture of the globe, and the word was considered to be the related nontarget. Again, the target elicited a large P300. However, in this case the related nontarget stimulus failed to elicit a P300. The relevance of the data to theories of word/picture processing is discussed.

Descriptors: Event-related potentials, P300, Nontarget P300, Similarity

The P300 is an endogenous component of the human event-related potential (ERP) that has been studied extensively in both clinical and experimental settings. Changes in P300 amplitude, latency, and scalp topography have been correlated with a number of psychometric and cognitive variables. (For reviews, see Picton, 1992; Pritchard, 1981.) Most notably, the P300 has been considered to be associated with the orienting response (Ritter, Vaughan, & Costa, 1968), updating of working memory (Donchin & Coles, 1988), and closure of perceptual events (Verleger, 1988).

The most frequently used paradigm in P300 research has been the two-stimulus oddball task, in which a participant must discriminate between infrequent target and frequent nontarget stimuli. In these paradigms, the infrequent, task-relevant target stimulus is associated with large P300 components with maximal amplitude at posterior electrodes. Modifications of the traditional oddball paradigm have also been employed, including passive tasks (e.g., Squires & Ollo, 1999), single-stimulus (e.g., Polich, Eischen, & Collins, 1994), and three-stimulus oddball paradigms (e.g., Courchesne, Hillyard, & Galambos, 1975). Thus, although the two-stimulus paradigm is typical in the literature, the P300 can be elicited in a variety of experimental contexts.

The use of the three-stimulus paradigm has demonstrated that in addition to the classic “target” P300, a P300-like component can also be elicited by infrequent nontarget stimuli that are intermixed with more frequent “standard” stimuli. (See Courchesne et al., 1975, and Courchesne, Courchesne, & Hillyard, 1978, for the initial reports.) Previous authors have suggested that P300s to nontarget stimuli represent an involuntary orienting response to novel stimuli (e.g., Courchesne et al., 1975; Knight, 1984), possibly mediated by an interaction between frontal and posterior cortical sites (Soltani & Knight, 2000). Compared to target P300s, nontarget P300s have been found to have different scalp distributions, latencies, and amplitudes (Courchesne et al., 1975, 1978). Depending on specific experimental manipulations, P300s elicited by infrequent nontarget stimuli have been labeled as “novelty P300s” (e.g., Courchesne et al., 1975), “no-go P300s” (e.g., Courchesne et al., 1978), or P3as (e.g., Comerchero & Polich, 1998). However, there is no consensus in the literature for the choice of the appropriate nomenclature for P300s to infrequent nontarget stimuli (Katayama & Polich, 1998). For the sake of simplicity, the theoretically neutral term “nontarget P300” will be used in the present article.

Recent studies have further explored the properties of nontarget P300s in three-stimulus paradigms (e.g., Comerchero & Polich, 1998, 1999; Katayama & Polich, 1996, 1998). It was found that target and nontarget P300s are differentially sensitive to the effects of stimulus context. Although the amplitude of the target P300 is influenced by its similarity to frequent standard stimuli, it is unaffected by the perceptual aspects of infrequent nontarget stimuli. However, P300s to infrequent nontarget stimuli are influenced by the perceptual context of both target and infrequent standard stimuli (Katayama & Polich, 1998). It has

The authors would like to thank Dr. Shlomo Bentin and two anonymous reviewers for insightful comments and suggestions on previous versions of the manuscript.

A portion of these data were presented at the 2003 annual meeting of the Society for Psychophysiological Research, Chicago, Illinois.

Address reprint requests to: Todd D. Watson, Department of Psychology, Stony Brook University, Stony Brook, NY 11794-2500, USA. E-mail: twatson@ic.sunysb.edu.

also been shown that for auditory stimuli, the perceptual distinctiveness of the infrequent nontarget and target stimuli directly influences the amplitude and topography of nontarget P300s (Comerchero & Polich, 1998). In summary, these studies have demonstrated that the relationship between nontarget and target stimuli affects the properties of nontarget P300s.

Several recent studies in our laboratory have also examined the ERP correlates of the processing of nontarget stimuli that are qualitatively similar to a target (Azizian, Freitas, Watson, & Squires, 2004; Azizian, Watson, Berry, Morris, & Squires, 2004). A major difference between our paradigm and previous paradigms is that we have used multiple stimuli that all occur with the same probability. This allows us to use the ERP to index the brains' spontaneous categorization of stimuli. In the first of our studies, we used a modified multistimulus oddball paradigm in which nine categories of stimuli were presented with equal probability. These categories included different types of human faces and nonhuman objects. One category of stimuli (black-female faces) was designated as the target whereas the other eight categories were nontargets. Several categories of nontarget stimuli were qualitatively similar to the target stimuli (e.g., black-male and white-female faces), whereas other categories of stimuli were dissimilar to the targets (e.g., male watches).

As expected, we found that target stimuli elicited prominent P300 components. Nontarget stimuli that were similar to the target exhibited P300s that were similar to but smaller in amplitude than those elicited by target stimuli. P300 amplitudes for both target and similar-to-target stimuli were greater than for stimuli that were dissimilar to the target. These data suggested that P300 amplitude is a useful index of similarity between a target and nontarget stimuli. As opposed to the results of studies using the three-stimulus oddball paradigm, the changes in amplitude of nontarget P300s seen in this study were independent of the effects stimulus probability.

A drawback of this previous study was that it was difficult to distinguish the effects of conceptual and perceptual/physical similarity between a target and nontarget stimuli. Similar-to-target stimuli were *both* conceptually and perceptually related to the target stimuli. For instance, while target and nontarget stimuli shared features that are commonly considered conceptual, such as race (black/white) and gender (male/female), they also shared common perceptual features such as color contrast, facial morphology, and hair length.

The purpose of the current studies was to examine the effects of conceptual similarity between target and nontarget stimuli on nontarget P300 amplitude. Participants were presented with a modified multistimulus oddball paradigm composed of five pictures and their five corresponding names. All stimuli appeared with equal probability. Studies of the Stroop effect in picture-word paradigms have suggested that activation of a particular concept in semantic memory can automatically activate its corresponding phonological representation in the lexicon (see MacLeod, 1991, for a review). In the current experiments, it was therefore assumed that at the level of lexical representation, printed words and their conceptually related pictures activate the same phonological unit. However, it is important to note that picture and word stimuli were perceptually distinct.

Two counterbalanced studies ("word" as target and "picture" as target) were performed. In the first study, the word "globe" was designated as the target stimulus. We hypothesized that the target stimulus would elicit a prominent P300 component. We also hypothesized that the related nontarget stimulus (picture of

a globe) would elicit a significant nontarget P300. The remaining nontarget stimuli were both perceptually and conceptually distinct from the target, and therefore were expected to elicit minimal P300 activity.

EXPERIMENT 1

Methods

Participants

Sixteen Stony Brook University students (age $M = 21.32$ years, $SD = 3.03$ years; 5 women) participated in the study. One participant's data were excluded because he or she failed to follow the experimental instructions. Participants gave informed consent and received extra credit for their undergraduate psychology courses. All participants had normal or corrected-to-normal vision.

Stimuli

Stimuli consisted of pictures of five simple objects derived from the Boston Naming Test and their corresponding names (see Figure 1). The word "globe" was designated as the target stimulus, and the picture of the globe was a priori considered to be the related nontarget stimulus. Two blocks of stimuli were presented in a pseudorandom fashion with 150 stimuli in each block. All stimuli were presented in with equal probability (.10).

Procedure

The study was conducted in a sound-attenuating chamber. Prior to each block of stimuli, we instructed participants to keep a silent mental count of the number of times the target appeared on the screen. Following each block, we asked the participants to report this count. No instructions were given with regards to any of the nontarget stimuli.

Stimuli were presented on a 12-in. flat-panel LCD. Participants were seated 2 ft from the LCD, and the center of the screen was at eye level. To minimize eye movements, participants were instructed to attend to a centered fixation point that was displayed for the duration of the experiment. We instructed participants to remain as still as possible and to minimize eyeblinks. Participants were allowed to rest between blocks.

ERP and Experimental Parameters

EEG activity was recorded using 64-channel electrode caps. A fronto-central electrode was used as a ground, and recordings

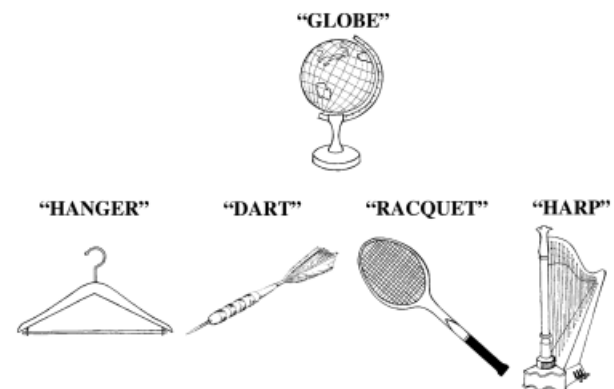


Figure 1. Word and picture stimuli used in the study.

were referenced to electronically linked mastoid electrodes. The horizontal EOG was monitored from electrodes at the outer canthi of the eyes, and the vertical EOG was monitored above and below the orbital region of the left eye. Electrode impedances did not exceed 10 k Ω . EEG and EOG activity were recorded using a gain of 1000 and a bandpass of 0.1 to 30 Hz. To eliminate artifacts, trials with EEG voltages exceeding $\pm 50 \mu\text{V}$ were rejected from the average. Approximately 10–15% of trials were excluded due to EOG or other artifacts.

Stimuli were presented for 500 ms with an interstimulus interval of 1000 ms. ERP epochs were acquired from 100 ms before the onset of each stimulus and continuing for 900 ms after presentation. For each participant, individual ERP averages were created for each of the 10 stimuli. Grand average waveforms were also created. Based on examination of these grand average waveforms, the P300 component for each individual was defined as the largest positive-going peak in a latency window of 375 to 525 ms. Peak ERP amplitude during the latency window was measured relative to the prestimulus baseline. All averaging and peak detections were performed off-line.

To reduce the number of statistical comparisons made in this study, while allowing for analysis of differences in the anterior–posterior and hemispheric dimensions, the data from only nine electrodes were statistically analyzed. The electrodes selected correspond to the International 10–20 system sites F₃, F_Z, F₄, C₃, C_Z, C₄, P₃, P_Z, and P₄. Data were analyzed using $3 \times 3 \times 10$ within-subjects analysis of variance (ANOVA). The variables examined were (1) anterior vs. posterior distributions (frontal,

central, parietal), (2) laterality (left, midline, right), and (3) stimulus type. Two participants had a single bad electrode (different for each participant). The group mean for the appropriate electrode/stimulus type combination was substituted in both cases. The Greenhouse–Geisser correction was used for all comparisons with more than two levels, and an alpha level of .05 was used for all analyses. Effect sizes are reported as partial-eta squares.

Results

Behavioral Data

Counting accuracy for the ERP study was high, with no participant reporting a count greater than 3% different from the correct count for target stimuli.

ERP Waveforms

Figure 2 displays grand average waveforms for the target (word “globe”), related nontarget (picture of a globe), and the remaining nontarget stimuli at nine electrode sites. The target stimulus elicited a large P300 response that was maximal over the vertex. The related nontarget stimulus elicited a P300 response that was morphologically similar but smaller in amplitude than the target P300. However, the onset of the target P300 response was earlier than the onset of the nontarget P300 response. No other nontarget stimulus elicited a significant P300 response. Figure 3 displays 64-channel ERP distribution maps for the target, related nontarget, and the remaining nontarget stimuli.

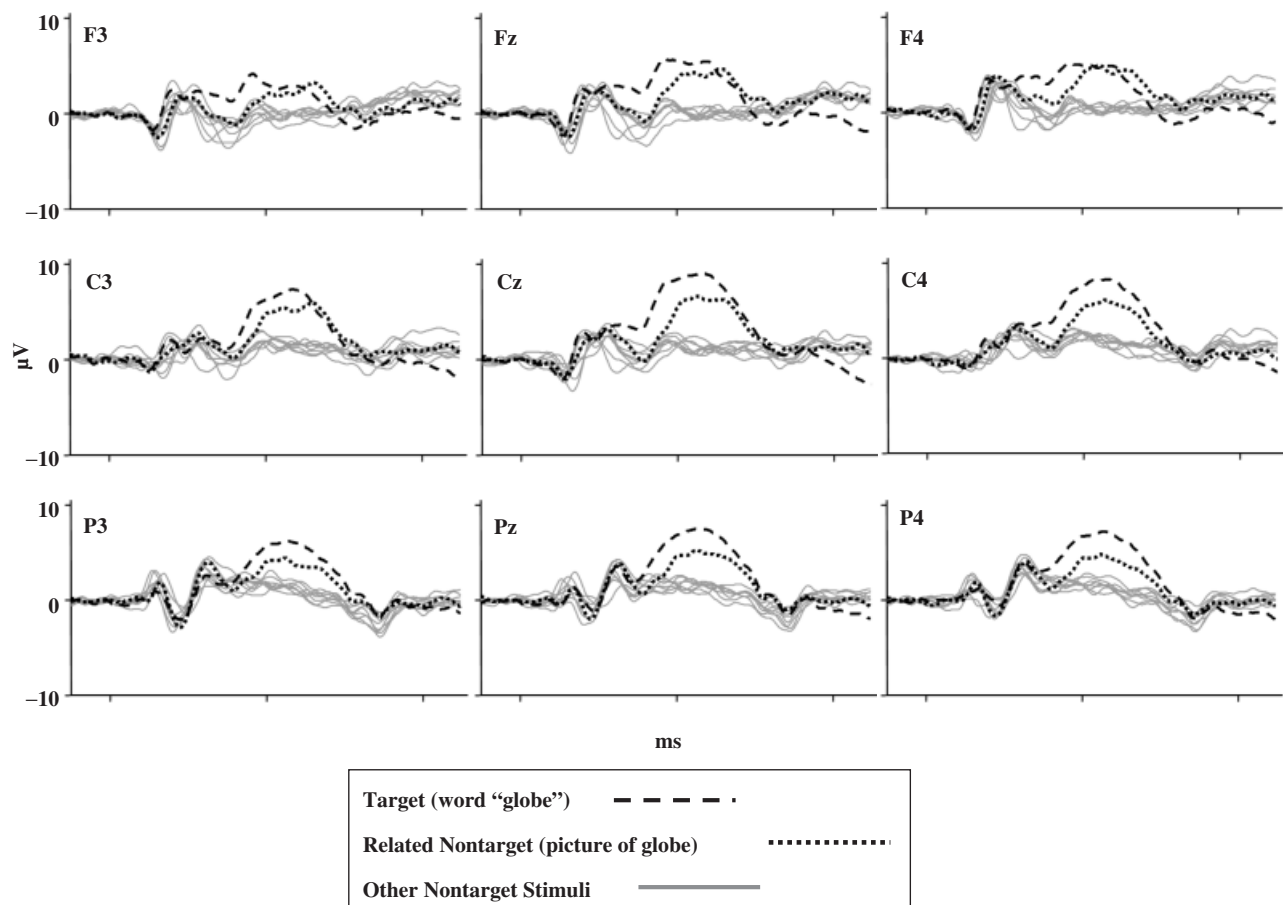


Figure 2. Grand average ERP waveforms for target (word “globe”), related nontarget (“picture of globe”), and other nontarget stimuli.

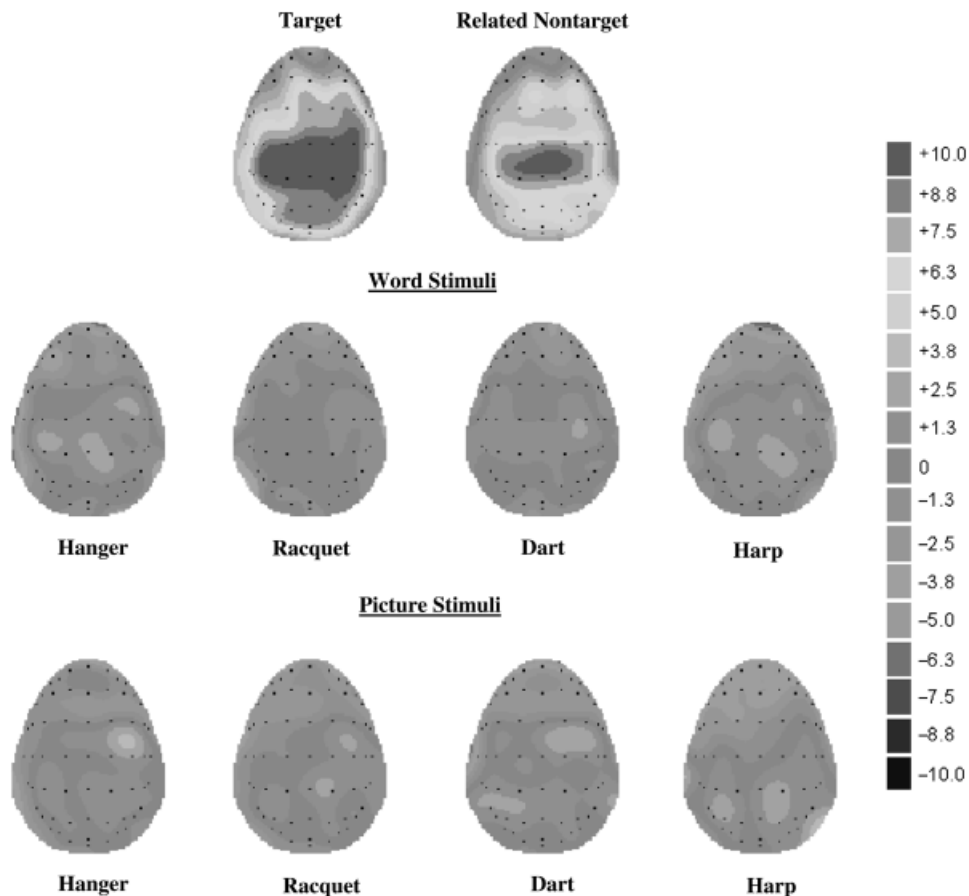


Figure 3. Sixty-four-channel ERP distribution maps taken at latency of peak P300 amplitude for target stimulus.

Statistical Comparisons

P300 amplitude. A significant main effect was found for anterior/posterior electrode distribution, $F(2,28) = 7.42$, $p < .01$, $\eta_p^2 = .35$. Simple comparisons revealed that P300 amplitude was significantly greater at central electrode sites ($4.92 \mu\text{V}$, $SE = 0.59$) than at frontal electrode sites ($3.14 \mu\text{V}$, $SE = 0.57$), $F(1,14) = 17.71$, $p = .001$, $\eta_p^2 = .56$. There was also a trend ($p = .07$) for P300 amplitude to be greater at parietal electrodes ($4.28 \mu\text{V}$, $SE = 0.55$) than frontal electrodes. No significant difference was found between central and parietal electrode sites.

A significant main effect for stimulus type was found, $F(9,126) = 12.51$, $p < .001$, $\eta_p^2 = .47$. Planned simple comparisons revealed that P300 amplitude was significantly greater for the target stimulus ($8.31 \mu\text{V}$, $SE = 0.78$) than for the related nontarget stimulus ($6.76 \mu\text{V}$, $se = 0.95$), $F(1,14) = 5.45$, $p = .04$, $\eta_p^2 = .28$, as well as for all other nontarget stimuli ($p < .001$, $\eta_p^2 > .67$ for all comparisons). As hypothesized, planned comparisons also revealed that amplitude was significantly greater for the related nontarget stimulus than for all other nontarget stimuli ($p < .03$, $\eta_p^2 > .30$ for all comparisons).

A significant Stimulus Type \times Laterality interaction was also found, $F(18,252) = 2.55$, $p = .03$, $\eta_p^2 = .15$. This effect seemed to be primarily driven by the large P300s to the target stimuli and related nontarget stimuli, whereas laterality effects were minimal for other nontarget stimuli. For both the target and related nontarget stimulus, amplitude at midline electrode sites was found to be significantly greater than for left hemisphere electrode sites,

$F(1,14) = 10.02$, $p < .01$, $\eta_p^2 = .42$ and $F(1,14) = 10.27$, $p < .01$, $\eta_p^2 = .42$, respectively.

P300 latency. Inspection of the grand average waveforms (see Figure 2) revealed that the onset of the P300 to target stimulus was earlier than the onset for the P300 response to the related nontarget stimulus. However, a one-way repeated-measures ANOVA revealed that there were no significant differences in peak P300 latency (defined by the latency of peak amplitude at electrode CZ for each stimulus type) between the target and related nontarget stimulus.

EXPERIMENT 2

A second, independent study was performed to determine if the effects of conceptual similarity between target and nontarget stimuli at the level of lexical representation could be replicated when a pictorial stimulus was designated as the target.

Methods

Participants

A separate group of 13 Stony Brook University students (age $M = 23.62$ years, $SD = 5.17$ years; 4 women) participated in Experiment 2. Participants gave informed consent and received extra credit for their undergraduate psychology courses. All participants had normal or corrected-to-normal vision.

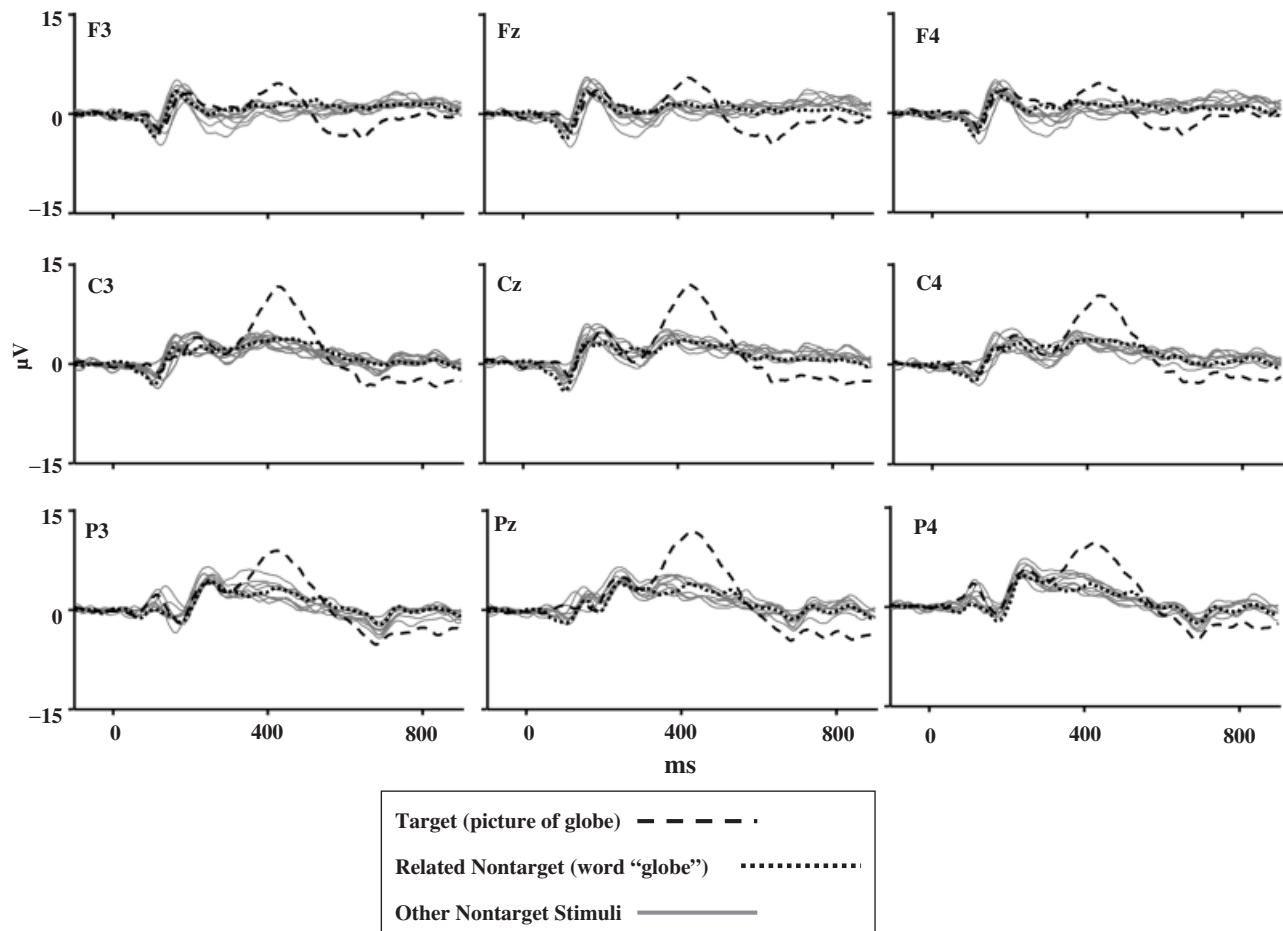


Figure 4. Grand average ERP waveforms for target (picture of globe), related nontarget (word “globe”), and other nontarget stimuli.

Stimuli, Procedure, and Experimental Parameters

The stimuli, procedures, and task parameters were identical to those used in Experiment 1, with the exception that the picture of a globe was designated as the target stimulus, and the word “globe” was a priori considered to be the related nontarget stimulus. The ERP recording and averaging parameters, as well as the statistical analysis plans were also identical to those used in Experiment 1.

RESULTS

Behavioral Data

As with Experiment 1, counting accuracy for the ERP study was high, with no participant reporting a count greater than 3% different from the correct count.

ERP Waveforms

Figure 4 displays grand average waveforms for the target (picture of a globe), related nontarget (word “globe”), and the remaining nontarget stimuli at nine electrode sites. The target stimulus elicited a large P300 response that was maximal over the vertex. Figure 5 displays 64-channel ERP distribution maps for the target, related nontarget, and the remaining nontarget stimuli. As opposed to the results of Experiment 1, the related nontarget stimulus failed to generate a prominent P300 effect. It should also be noted that P300 amplitude for the target stimulus was greater than it was for Experiment 1. Accordingly, the amplitude scale of the figures is different.

Statistical Comparisons

P300 amplitude. A significant main effect was found for anterior/posterior electrode distribution, $F(2,24) = 14.95$, $p = .001$, $\eta_p^2 = .56$. Simple comparisons revealed that peak ERP amplitude between 375 and 525 ms was significantly greater at central electrode sites ($6.76 \mu\text{V}$, $SE = 0.65$) than at frontal electrode sites ($3.99 \mu\text{V}$, $SE = 0.30$), $F(1,12) = 21.07$, $p = .001$, $\eta_p^2 = .64$, and parietal electrode sites ($5.89 \mu\text{V}$, $SE = 0.65$), $F(1,12) = 18.65$, $p = .001$, $\eta_p^2 = .61$. ERP amplitude was also significantly greater at parietal sites than at frontal electrode sites, $F(1,12) = 8.99$, $p = .01$, $\eta_p^2 = .43$.

A significant main effect for laterality was also found, $F(2,24) = 6.60$, $p < .01$, $\eta_p^2 = .36$. Simple comparisons revealed that peak ERP amplitude at midline electrode sites ($5.93 \mu\text{V}$, $SE = 0.52$) was significantly greater than both left hemisphere electrode sites ($5.36 \mu\text{V}$, $SE = 0.43$), $F(1,12) = 7.16$, $p = .02$, $\eta_p^2 = .37$, and right hemisphere electrode sites ($5.35 \mu\text{V}$, $SE = 0.49$), $F(1,12) = 15.94$, $p < .01$, $\eta_p^2 = .57$.

As expected, a significant main effect for stimulus type was found, $F(9,108) = 9.91$, $p < .001$, $\eta_p^2 = .45$. Planned simple comparisons revealed that peak amplitude was significantly greater for the target stimulus ($10.44 \mu\text{V}$, $SE = 1.07$) than for the related nontarget stimulus ($4.84 \mu\text{V}$, $SE = 0.44$), $F(1,12) = 35.87$, $p < .001$, $\eta_p^2 = .75$, as well as for all other nontarget stimuli ($p < .01$, $\eta_p^2 > .53$ for all comparisons). As opposed to the results

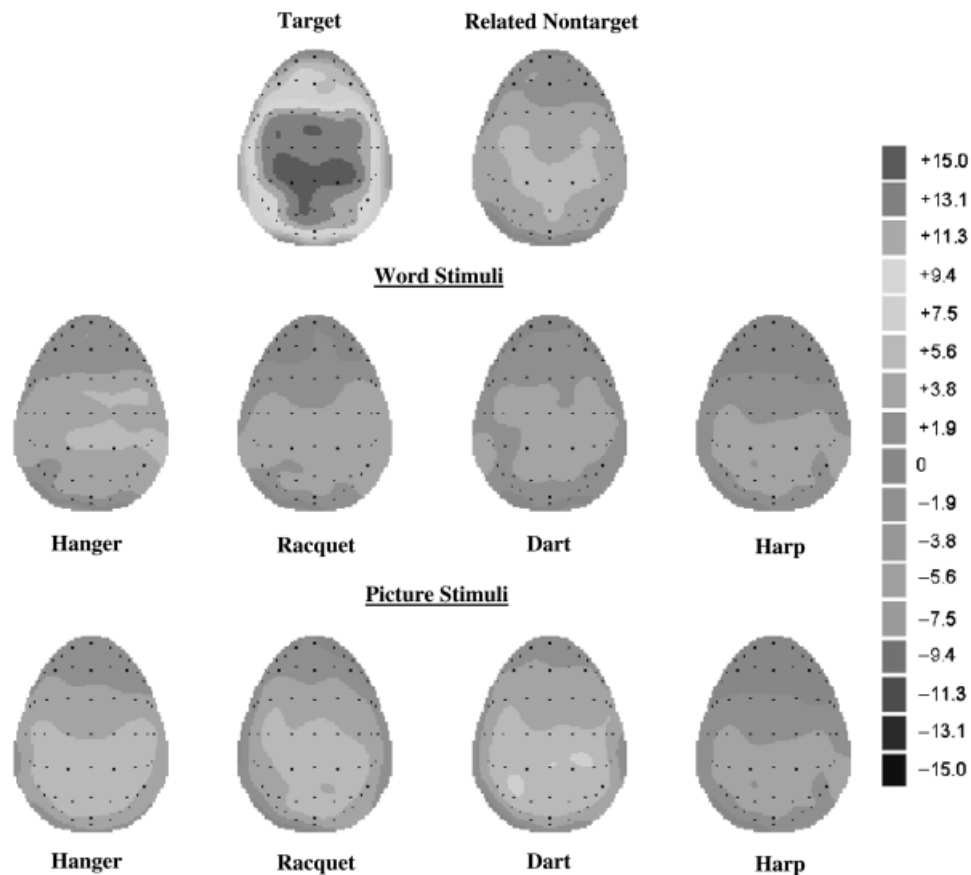


Figure 5. Sixty-four-channel ERP distribution maps taken at latency of peak P300 amplitude for target stimulus.

of Experiment 1, no significant difference in ERP amplitude was found between the related nontarget stimulus and any other nontargets. A significant Stimulus Type \times Anterior/Posterior interaction was also found, $F(18,216) = 3.61$, $p < .01$, $\eta_p^2 = .23$. This effect seemed to be primarily driven by the large P300s to the target stimuli, whereas differences in anterior/posterior scalp distributions were less pronounced for nontarget stimuli.

P300 latency. A one-way repeated-measures ANOVA revealed no significant differences in peak P300 latency between the target and related nontarget stimulus.

Discussion

Experiment 1

These studies examined the ERP correlates of processing a nontarget stimulus that is conceptually (at the level of lexical representation), but not perceptually, related to a target. It was assumed at the lexical level, the target (the word “globe”) and related nontarget stimulus (picture of a globe) activated the same phonological unit. As expected, the target stimulus elicited a large P300 component with maximum amplitude over the vertex. The related nontarget stimulus elicited a P300 that was morphologically similar to but significantly smaller in amplitude than the target P300. No other nontarget stimuli elicited a prominent P300 component.

The results of Experiment 1 supported our hypothesis that the level of similarity between a target and nontarget stimulus is correlated with nontarget P300 amplitude. More specifically, the data indicated that nontarget P300 amplitude is affected when a nontarget stimulus activates the same mental representation as the target stimulus. This effect appears to be independent of perceptual similarities between target and nontarget stimuli. Overall, the data from Experiment 1 indicate that nontarget P300 amplitude is a potentially useful index of how the brain defines relationships between perceptually distinct stimuli.

The results of Experiment 1 are consistent with the hypothesis that ERPs can be used to index both voluntary and involuntary components of the human attentional and memory systems. For example, numerous studies have demonstrated that semantic priming affects the amplitude and/or latency of several ERP components (e.g., Bentin, 1987; Bentin, McCarthy, & Wood, 1985; Chwilla, Brown, & Hagoort, 1995; Nigam, Hoffman, & Simmons, 1992; Niznikiewicz & Squires, 1996). Many of these studies utilized a lexical decision task, a classic experimental paradigm in which participants are required to decide if a target word is a real word or a pseudo-word. If the target word is preceded by a semantically related (as opposed to an unrelated) word, then reaction times for the lexical decision are faster. ERPs have been shown to be a useful physiological marker of this effect. Semantically primed targets have consistently been shown to elicit a significantly smaller N400 than an unrelated target. These effects have also been demonstrated using semantic priming with line drawings (e.g., Barrett & Rugg, 1990; Holcomb &

McPherson, 1994) and, similar to the current studies, for cross-modal priming using line drawings and words (e.g., Ganis, Kutas, & Sereno, 1996; Nigram et al., 1992).

Although ERP studies of semantic priming have often focused on the N400, the P300 also appears to be sensitive to the effect. For example, Bentin and colleagues (1985) reported that P300 latency is significantly reduced for semantically primed targets. Targets were also associated with increased P300 amplitude. More recently, it has been demonstrated that the P300 is also useful as an index of the degree of semantic relatedness between primes and targets (Hill, Strube, Roesch-Ely, & Weisbrod, 2002). The authors found increased P300 amplitude for targets that had a *direct* semantic relationship with the prime, as well as for targets that had only an *indirect* semantic relationship with the prime compared to targets that were unrelated to the prime and pseudo-word targets. Similarly, McPherson and Holcomb (1999) demonstrated that long latency ERP negativities can differentiate the level of relationship between primes and targets using pictorial stimuli. The results of Experiment 1 of the present study extend these findings by suggesting that the degree of similarity between stimuli can be indexed physiologically using a multistimulus oddball paradigm.

Experiment 2

Interestingly, the results of Experiment 2 did not conform to our predictions. Whereas the target stimulus (picture of a globe) produced a large P300 response, the related nontarget stimulus (word "globe") did not produce a nontarget P300 response. The reasons why such disparate results were found in Experiment 1 and Experiment 2 are unclear. However, these data could be interpreted in light of theories such as the dual-coding model, that suggest that words and pictures can be processed independently, even if they share a common meaning. (See Pavio, 1991, for a review.) In this model, it is assumed that imagery and verbal information are processed by distinct but interconnected systems. The interconnections could lead to the cross-activation of corresponding units of information held in the two independent systems, although this cross-activation does not necessarily always occur. A number of previous ERP studies have supported the hypothesis that pictures and words are processed differently. (See Greenham, Stelmack, & Campbell, 2000, for a brief review.)

ERP studies have also been successful in directly validating the predictions of the dual-coding model. For example, the dual-

coding model proposes that easily imageable (concrete) words are processed differently than abstract words. Several ERP studies have reported dissociations between N400 topography for concrete and abstract words under several experimental conditions (e.g., Kounios & Holcomb, 1994; Nittono, Suehiro, & Hori, 2002). Differences in N400 topography between picture and word targets were found in a cross-form semantic priming study (Ganis et al., 1996), which can also be interpreted as support for the dual-coding model (McPherson & Holcomb, 1999).

Distinct processing circuits for imagery (pictures) and verbal information could account for the differential effects of picture and word targets reported in this Experiment 2. Previous work has found similar dissociations. Glaser and Glaser (1989) suggest that word stimuli have "privileged access" to the lexicon, whereas pictorial stimuli have "privileged access" to the semantic network. The authors found that when engaged in semantic categorization of words in a modified Stroop task, a picture from another semantic category causes strong inhibition. However, when participants were required to categorize pictures, words from another semantic category caused no inhibition (Glaser & D ngelhoff, 1984; Glaser & Glaser, 1989). It has also been demonstrated that ERP indices of cross-modal priming can be one directional (e.g., Friedman, Cycowicz, & Dziobek, 2003; Kazmerski & Friedman, 1997). Interestingly, Kazmerski and Friedman found that in the cross-form (word–picture or picture–word) condition of a direct recognition memory task, significant ERP repetition priming effects were found when pictorial targets were previously seen as words, but not when word targets were previously seen as pictures.

Although the results of Experiment 2 seem to support cognitive models that propose separate processing streams for pictorial and verbal stimuli, it is important to note that the study was not specifically designed to test these hypotheses. Therefore, the interpretation of the data in this light should be regarded as speculative. However, taken with the results of Experiment 1, the data do suggest that the nontarget P300 amplitude recorded in a multistimulus oddball paradigm might not only be a useful index of similarity between perceptually distinct stimuli, but also as a physiological marker of how the brain might process stimuli that activate similar mental representations differently. This opens the way for more directed use of the paradigm in testing hypotheses such as those proposed by the dual-coding model.

REFERENCES

- Azizian, A., Freitas, A. L., Watson, T. D., & Squires, N. K. (2004). Neurophysiological correlates of distinguishing simple and complex targets from perceptually similar non-targets: Implications for theories of categorization. Manuscript submitted for publication.
- Azizian, A., Watson, T. D., Berry, S., Morris, J. P., & Squires, N. K. (2004). P300 amplitude as an index of perceptual and conceptual similarity. Manuscript submitted for publication.
- Barrett, S. E., & Rugg, M. D. (1990). Event-related potentials and the semantic matching of pictures. *Brain and Cognition*, *14*, 201–212.
- Bentin, S. (1987). Event-related potentials, semantic processes, and expectancy factors in word recognition. *Brain and Language*, *31*, 308–327.
- Bentin, S., McCarthy, G., & Wood, C. C. (1985). Event-related potentials, lexical decision, and semantic priming. *Electroencephalography and Clinical Neurophysiology*, *60*, 343–355.
- Chwillla, D. J., Brown, C. M., & Hagoort, P. (1995). The N400 as a function of the level of processing. *Psychophysiology*, *32*, 274–285.
- Comerchero, M. D., & Polich, J. (1998). P3a, perceptual distinctiveness, and stimulus modality. *Cognitive Brain Research*, *7*, 41–48.
- Comerchero, M. D., & Polich, J. (1999). P3a and P3b from typical auditory and visual stimuli. *Clinical Neurophysiology*, *110*, 24–30.
- Courchesne, E., Courchesne, R. Y., & Hillyard, S. A. (1978). The effect of stimulus deviation on P3 waves to easily recognized stimuli. *Neuropsychologia*, *16*, 189–199.
- Courchesne, E., Hillyard, S. A., & Galambos, R. (1975). Stimulus novelty, task relevance and the visual evoked potential in man. *Electroencephalography and Clinical Neurophysiology*, *39*, 131–143.
- Donchin, E., & Coles, M. G. H. (1988). Precommentary: Is the P300 component manifestation of context updating? *Behavioral and Brain Science*, *11*, 357–374.
- Friedman, D., Cycowicz, Y. M., & Dziobek, I. (2003). Cross-form conceptual relations between sounds and words: Effects on the novelty P3. *Cognitive Brain Research*, *18*, 58–64.

- Ganis, G., Kutas, M., & Sereno, M. (1996). The search for "common sense": An electrophysiological study of the comprehension of words and pictures in reading. *Journal of Cognitive Neuroscience*, *8*, 89–106.
- Glaser, W. R., & Dünghoff, F.-J. (1984). The time course of picture-word interference. *Journal of Experimental Psychology Human Perception and Performance*, *10*, 640–654.
- Glaser, W. R., & Glaser, M. O. (1989). Context effects in Stroop-like word and picture processing. *Journal of Experimental Psychology: General*, *118*, 13–42.
- Greenham, S. L., Stelmack, R. M., & Campbell, K. B. (2000). Effects of attention and semantic relation on event-related potentials in a picture-word naming task. *Biological Psychology*, *50*, 79–104.
- Hill, H., Strube, M., Roesch-Ely, D., & Weisbrod, M. (2002). Automatic vs. controlled processes in semantic priming—Differentiation by event-related potentials. *International Journal of Psychophysiology*, *44*, 197–218.
- Holcomb, P. J., & McPherson, W. B. (1994). Event-related potentials reflect semantic priming in an object decision task. *Brain and Cognition*, *24*, 257–276.
- Katayama, J., & Polich, J. (1996). P300 probability, and the three-tone paradigm. *Electroencephalography and Clinical Neurophysiology*, *100*, 555–562.
- Katayama, J., & Polich, J. (1998). Stimulus context determines P3a and P3b. *Psychophysiology*, *35*, 23–33.
- Kazmerski, V. A., & Friedman, D. (1997). Old/new differences in direct and indirect memory tests using pictures and words in within and cross-forms conditions: Event-related potential and behavioral measures. *Cognitive Brain Research*, *5*, 255–272.
- Knight, R. T. (1984). Decreased response to novel stimuli after prefrontal lesions in man. *Electroencephalography and Clinical Neurophysiology*, *59*, 133–139.
- Kounios, J., & Holcomb, P. J. (1994). Concreteness effects in semantic processing: ERP evidence supporting dual-coding theory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 804–823.
- MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, *109*, 163–203.
- McPherson, W. B., & Holcomb, P. J. (1999). An electrophysiological investigation of semantic priming with pictures of real objects. *Psychophysiology*, *36*, 53–65.
- Nigam, A., Hoffman, J., & Simons, R. (1992). N400 to semantically anomalous pictures and words. *Journal of Cognitive Neuroscience*, *4*, 15–22.
- Nitto, H., Suehiro, M., & Hori, T. (2002). Word imageability an N400 in an incidental memory paradigm. *International Journal of Psychophysiology*, *44*, 219–229.
- Niznikiewicz, M., & Squires, N. K. (1996). Phonological processing and the role of strategy in silent reading: Behavioral and electrophysiological evidence. *Brain and Language*, *52*, 342–364.
- Paivio, A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology*, *45*, 255–287.
- Picton, T. W. (1992). The P300 wave of the human event-related potential. *Journal of Clinical Neurophysiology*, *9*, 456–479.
- Polich, J., Eischen, S. E., & Collins, G. E. (1994). P300 from a single auditory stimulus. *Electroencephalography Clinical Neurophysiology*, *92*, 253–261.
- Pritchard, W. S. (1981). Psychophysiology of P300. *Psychological Bulletin*, *89*, 506–540.
- Ritter, W., Vaughan, H. G., & Costa, L. D. (1968). Orienting and habituation to auditory stimuli: A study of short term changes in average evoked responses. *Electroencephalography and Clinical Neurophysiology*, *25*, 550–556.
- Soltani, M., & Knight, R. T. (2000). Neural origins of the P300. *Critical Reviews in Neurobiology*, *14*, 199–224.
- Squires, N. K., & Ollo, C. (1999). Comparison of endogenous event-related potentials in attend and non-attend conditions: Latency changes with normal aging. *Clinical Neurophysiology*, *110*, 564–574.
- Verleger, R. (1988). Event-related potentials and cognition: A critique of the context updating hypothesis and an alternative interpretation of P3. *Behavioral and Brain Sciences*, *11*, 343–356.

(RECEIVED May 4, 2004; ACCEPTED January 21, 2005)