

# Beware misleading cues: Perceptual similarity modulates the N2/P3 complex

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## Abstract

Event-related potentials were used to investigate neural processes relating perceptual similarity to action control. To assess whether perceptual overlap among targets and nontargets would modulate the N2/P3 complex, the present study used multiple nontarget categories varying in their targetlike characteristics. Participants made one (relatively rare) response to a low-probability stimulus (target), and they made a different (relatively common) response to all other stimuli (nontargets). The critical nontarget categories had equivalent probability (.10) but varied in their targetlike characteristics. Supporting the N2 component as sensitive to the strength of conflicting action imperatives, perceptual overlap among targets and nontargets elicited a prominent N2. In contrast, amplitude of the P3 component appeared most sensitive to the extent of cognitive processing needed for categorization.

**Descriptors:** ERPs, Event-related potentials, P3, N2, Choice RT, Perceptual similarity, Categorization, Conflict monitoring

Pursuing any particular course of action requires overcoming competing tendencies triggered by the many cues typically present in one's thoughts and environment. A motorist who needs to turn left at North Nitch Street but not North Hitch Street, an athlete passing a soccer ball to a teammate but not an opponent, or a police officer firing upon a gun-wielding criminal but not a wallet-toting bystander, for example, all need to decide quickly how to treat ambiguous stimuli. Understanding how people exert control over their actions despite such challenges has been a major focus of diverse research efforts (e.g., Allport, 1987; Baddeley & Della Sala, 1996; Bush, Valera, & Seidman, 2005; Freitas, Liberman, & Higgins, 2002; Mischel, Shoda, & Rodriguez, 1989; Monterosso, Aron, Cordova, Xu, & London, 2005; Norman & Shallice, 1986; Rachlin, 2000; Ridderinkhof & van den Wildenberg, 2005).

These issues have been investigated extensively in the choice reaction-time (RT) and go/no-go paradigms, in which correct performance often entails overcoming habitual responses (Braver, Barch, Gray, Molfese, & Snyder, 2001). Event-related potential (ERP) studies demonstrate that stimuli with low-frequency responses entail an enhanced frontally distributed

negative deflection (N2), maximal between around 200 and 300 ms (e.g., Nieuwenhuis, Yeung, Van den Wildenberg, & Ridderinkhof, 2003; Simson, Vaughan, & Ritter, 1977). Recent research indicates that the N2 is not specific to no-go response inhibition and is present when there is a tendency to make prepotent but incorrect responses (Donkers & van Boxtel, 2004). Thus, what has been defined generally as the no-go N2 component appears to reflect processes also underlying the go N2 component, when, for example, go responses are generated much less frequently than are no-go responses (Nieuwenhuis et al., 2003). Topographical distributions and dipole analysis indicate that the N2 has a medial frontal generator most likely originating in the anterior cingulate cortex (ACC; Bekker, Kenemans, & Verbaten, 2005).

Research in cognitive neuroscience supports that the N2 component is sensitive to overcoming habitual/stereotypical responses rather than to inhibiting motor responses (e.g., Braver et al., 2001; Donkers & van Boxtel, 2004; Nieuwenhuis et al., 2003). This work has been related to conflict-monitoring tasks such as response competition, adjustments in perceptual selection, and maintenance of contextual information (for a review, see Botvinick, Braver, Barch, Carter, & Cohen, 2001). In this literature, conflict monitoring refers to situations in which an infrequent response must overcome the bias toward prepotent highly frequent responses (Botvinick, Cohen, & Carter, 2004). Supporting this model, ACC appears active in a wide range of tasks that demand overriding automatic but task-inappropriate response (Braver et al., 2001). Hence, regardless of the specific nature of the task (e.g., go/no-go, oddball, choice RT), ACC activation appears to accompany the generation of nonroutine

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responses. Although these different tasks certainly have unique features, at the conflict-monitoring level, they are similar to each other. For example, the go/no-go task involves infrequent response inhibition in the context of habitual responses, whereas choice RT involves generating an alternative response in the context of habitual responses. Thus, both tasks involve not only visual discrimination and simple choice but also arbitration between competing responses of varying prepotency.

Conflict-monitoring theories predict that increasing the perceptual overlap between stimuli that cue frequent and infrequent responses, by cuing conflicting action tendencies, should increase the size of the N2 (e.g., Folstein & Van Petten, 2004; Nieuwenhuis, Yeung, Cohen, 2004). In the single most direct test of this hypothesis, however, surprising modality differences emerged, with perceptual similarity moderating N2 effects to auditory but not visual stimuli (Nieuwenhuis et al., 2004). In that study, the letter "F," presented either auditorily or visually, served as subjects' go or no-go stimulus. Across separate auditory- and visual-stimulus blocks, the letter "F" was paired with either an "S" or a "T." Because an auditorily presented "F" resembles "S" more than "T," the authors predicted, and indeed found, a larger no-go N2 when the auditory no-go stimulus "F" was paired with "S" than when it was paired with "T." Likewise, a visually presented "F" resembles "T" more than "S." However, no difference emerged in the size of the N2 when the visual no-go stimulus "F" was paired with "T" or when it was paired with an "S." Thus, visual perceptual overlap did not appear to moderate the magnitude of the no-go N2.

On the other hand, in a study of how people categorize novel visual stimuli, Folstein and Van Petten (2004) found that participants exhibited heightened N2s when they categorized stimuli whose features placed them at the implicit boundary of two categories. The authors interpreted the effect as evidence of suppression of task-inappropriate responses that had been activated by perceptual overlap between the test stimulus and the multiple candidate categories. However, why visual perceptual overlap would augment the N2 in the Folstein and Van Petten (2004) study but not in Nieuwenhuis et al. (2004) study remains unclear.

The current study addressed this issue by manipulating whether the same visual stimuli served as similar or dissimilar nontargets in a choice RT paradigm. Many previous studies of this type have been confined to two classes of stimuli, in which response biases are manipulated by varying the frequency of each type of response and conflict is presumed to be particularly high when executing the infrequent response (rather than the frequent, prepotent response). In the current study, in contrast, there were multiple classes of nontargets. Participants made one (relatively rare) response to a low-probability stimulus (the target), and they made a different (relatively common) response to all other stimuli (the nontargets). Importantly, one class of the nontarget stimuli was perceptually similar to the target. We counterbalanced which stimulus served as participants' targets, so that the same nontarget stimuli served as similar nontargets for some participants but as dissimilar nontargets for other participants (see Figure 1). In accord with the above theorizing, we predicted a larger N2 response to similar than to dissimilar nontargets, because the similar nontargets were hypothesized to cue two conflicting responses, the "target" response as well as the "nontarget" response.

Another goal of the present study was to extend our recent finding that demonstrates equiprobable nontargets containing targetlike characteristics produce intermediate P3s (Azizian,

Freitas, Watson, & Squires, 2006; Watson, Azizian, Berry, & Squires, 2005). We have interpreted these intermediate P3s to reflect allocation of additional resources in categorizing similar nontargets. In initial tests of that hypothesis, however, participants silently counted targets rather than responding overtly to them, leaving open the possibility that intermediate P3s to similar nontargets partially reflect misclassification of some nontargets as targets. Because the current task requires responses to all stimuli, an error-based alternative account of its findings is unlikely. Accordingly, intermediate targetlike P3s to similar nontargets could replicate and extend our earlier P3 work while substantiating the experimental manipulation of nontargets' similarity for the present N2 study.

## Methods

### Participants

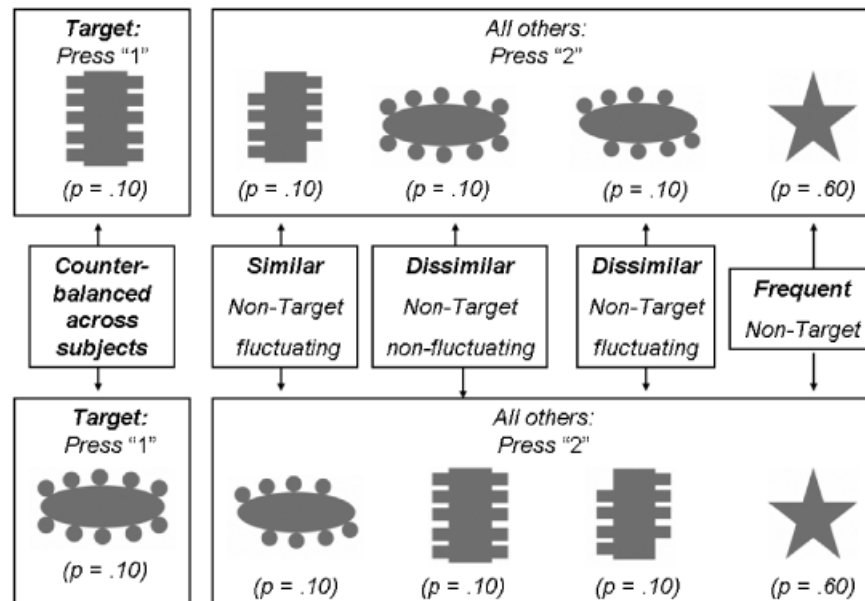
Seventeen right-handed individuals, eight men, between the ages of 18 and 28 (mean = 22.5) participated in the study. Participants had normal or corrected-to-normal vision and received course credits or money (\$15 an hour) for participation. Data from three participants were discarded due to insufficient artifact-free trials (<15). Data from an additional participant were discarded due to excessive movement artifact. All participants signed an informed consent written in accordance with the guidelines set by the Committee on Research Involving Human Subjects of Stony Brook University.

### Experimental Stimuli

The stimuli were composed of five geometric categories. Target categories were randomly counterbalanced across participants. Four stimulus categories occurred with equivalent 10% frequency, and frequent nontargets occurred with 60% frequency. This approach allowed comparison between target and three other stimulus categories of equal probability. Stimulus categories differed on whether there was a single exemplar (nonfluctuating) or many exemplars (fluctuating). As illustrated in Figure 1, the stimulus categories were defined as targets ( $p = .10$ ), similar nontargets fluctuating ( $p = .10$ ), dissimilar nontargets nonfluctuating ( $p = .10$ ), dissimilar nontargets fluctuating ( $p = .10$ ), and frequent nontargets ( $p = .60$ ). There were 30 stimulus presentations per category for a total of 300 stimuli per session, broken down into two experimental blocks. The fluctuating categories consisted of 30 within-class distinct stimuli. Figure 1 displays one single exemplar. Other fluctuating exemplars had a different feature missing. Stimulus duration was 500 ms, and the interstimulus interval was 1000 ms.

### Procedure

The experiment was conducted in a dark, sound-attenuating chamber, with participants seated comfortably in a reclining chair, approximately 61 cm from the screen. The stimuli were presented on a flat-panel LCD computer monitor in gray against a white background. The stimuli were 5.08 cm high by 5.08 cm wide. Participants were instructed to remain as still as possible and to minimize eyeblinks throughout the experiment. They were instructed to quickly and accurately press one of two response keys to discriminate between target and nontarget stimuli. The response pad consisted of a rectangular device with four buttons oriented horizontally. All responses were made by pressing either button 1 or button 4. The task was to press one button with the index finger of one hand if the stimulus was a target and with the



**Figure 1.** Illustration of stimuli used. For the fluctuating categories, the figure displays one exemplar. Other fluctuating exemplars had a different feature missing.

index finger of the other hand if the stimulus was a nontarget. Assignment of hand use was counterbalanced across participants. To ensure participants' proper understanding of the task, a short training block was administered.

#### **Electrophysiological Recording**

The EEG was recorded continuously using a 64-channel electrode cap (Neuroscan Inc., Sterling USA). All recordings were performed using a fronto-central electrode as ground, and electronically linked mastoid electrodes as reference. The horizontal EOG was monitored from electrodes at the outer canthi of the eyes, and the vertical EOG was monitored from electrodes above and below the orbital region of the left eye. Impedances for all electrodes were kept below 10 K $\Omega$ . The EEG and EOG signals were digitized at 1000 Hz and were amplified with a gain of 500. The filter bandpass was 0.01–30 Hz. To eliminate EOG artifact, trials with EEG voltages exceeding  $\pm 100 \mu\text{V}$  were rejected from the average. Artifact rejection and averaging were done off-line. Approximately 20% of the trials were excluded due to artifacts. ERP epochs began 100 ms prior to stimulus onset and continued for 900 ms thereafter.

#### **ERP Analysis**

Individual ERP averages were created for each stimulus category. The first negative peak in the latency range of 150–300 ms was designated the N2 component. The maximal positive peak following the N2 component was designated the P3 component. Peak amplitude was measured relative to the prestimulus baseline. Topographical maps (based on all 64 channels) at the time point of maximum N2 and P3 amplitude were taken to present scalp distribution. Given much previous evidence of important anterior–posterior differences in the distribution of each those components, we based our statistical analyses on data averaged from the middle five electrodes (i.e., AF4, FP2, FPZ, FP1, AF3) at each of the eight anterior–posterior rows (the most posterior row was based on the three electrodes O2, OZ, and O1). Figure 2 displays the layout of the electrode array used for statistical

analyses. The Greenhouse–Geisser correction was used for all comparisons with more than two within-subject levels.

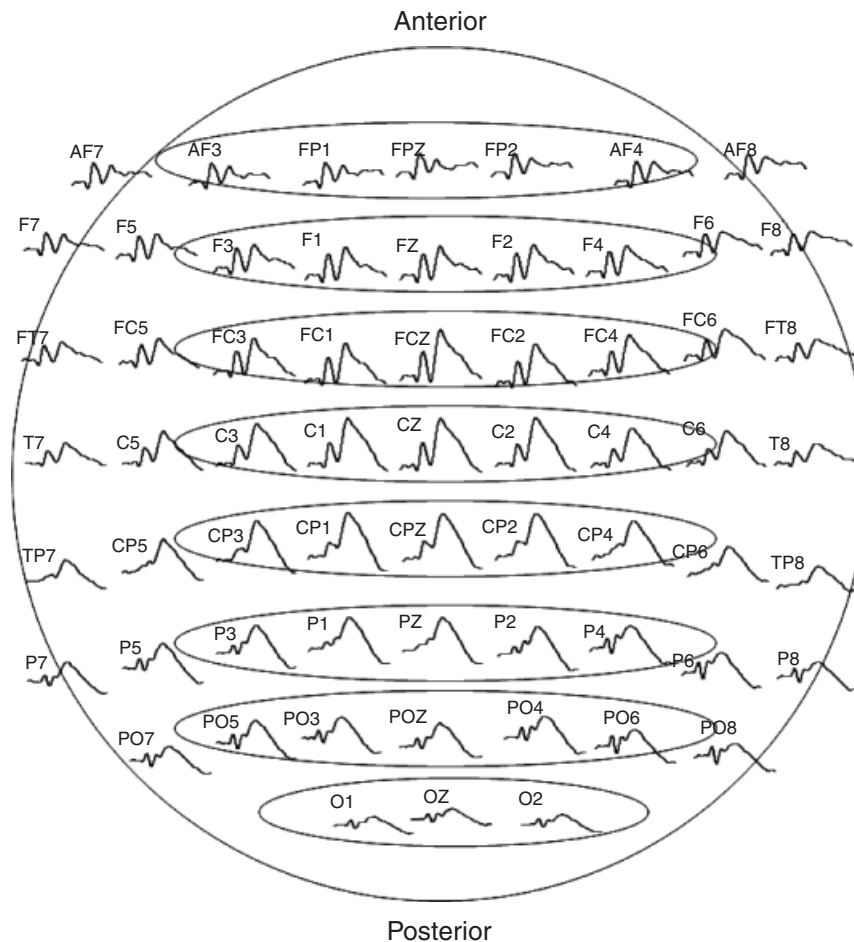
## **Results**

#### **Behavioral Results**

Participants' responses were correct on 98.38% of trials. Response times on incorrect trials were not analyzed. Table 1 presents the average response times and percentage of correct responses for each of the five stimulus types. As shown in a one-way repeated-measures ANOVA, average response times differed significantly across stimulus type,  $F(4,48) = 112.73$ ,  $p < .0001$ ,  $\eta_p^2 = .90$ . Most relevant to our investigation, and suggesting that we successfully manipulated the degree to which the different kinds of nontargets overlapped perceptually with the target, participants responded much more slowly (difference  $M = 109.70$  ms,  $SD = 36.30$  ms) to similar than to dissimilar nontargets (fluctuating),  $t(12) = 10.90$ ,  $p < .0001$ ,  $\eta_p^2 = .83$ .

#### **ERP Waveforms**

Figure 3 shows grand-average ERP waveforms for each stimulus category. Visual inspection of these waveforms indicates a larger N2 to similar nontargets at fronto-central scalp sites than to any other stimuli. The second prominent ERP characteristic is the P3 component, which is largest to targets and maximal at centroparietal electrode sites. Figure 4 displays 64-channel topographical voltage maps across the scalp at time points corresponding to the N2 and P3 components. In an omnibus analysis of all ERP amplitude data, a 2 (target assignment: rounded vs. right-angled, as shown in Figure 1)  $\times$  2 (peak: N2 vs. P3)  $\times$  5 (stimulus type: target, four types of nontargets)  $\times$  8 (anterior/posterior electrode location) ANOVA yielded significant effects of peak,  $F(7,84) = 141.27$ ,  $p < .0001$ ,  $\eta_p^2 = .93$ , which is not surprising, given the opposite polarity of the N2 and P3, the Peak  $\times$  Anterior/Posterior Electrode Location interaction,  $F(7,77) = 47.67$ ,  $p < .0001$ ,  $\eta_p^2 = .81$ , consistent with a more anterior-maximal N2 and posterior-maximal P3, the Peak  $\times$  Stimulus Type interaction,



**Figure 2.** Layout of the electrode array used for statistical analyses.

$F(4,44) = 18.76, p < .0001, \eta_p^2 = .63$ , consistent with possibility that the N2 and P3 were differentially sensitive to the different stimulus conditions, and the three-way interaction between peak, stimulus type, and anterior/posterior electrode location,  $F(4,44) = 18.76, p < .0001, \eta_p^2 = .63$ , suggesting that differences between N2 and P3 responses in particular stimulus conditions differed across anterior/posterior topographical loci. Moreover, participants' random assignment to the rounded versus right-angled targets (see Figure 1) neither impacted the overall amplitude of their electrophysiological responses,  $F(1,11) = 0.01$ , nor moderated any other main effects or interactions reported above, all  $F_s < 1.61, p_s > .23$ . Given this omnibus evidence that the N2 and P3 appeared differentially sensitive to the different

stimulus conditions, while unaffected by the particular targets participants were assigned, we next conducted focused tests of our hypotheses.

### The N2 Component

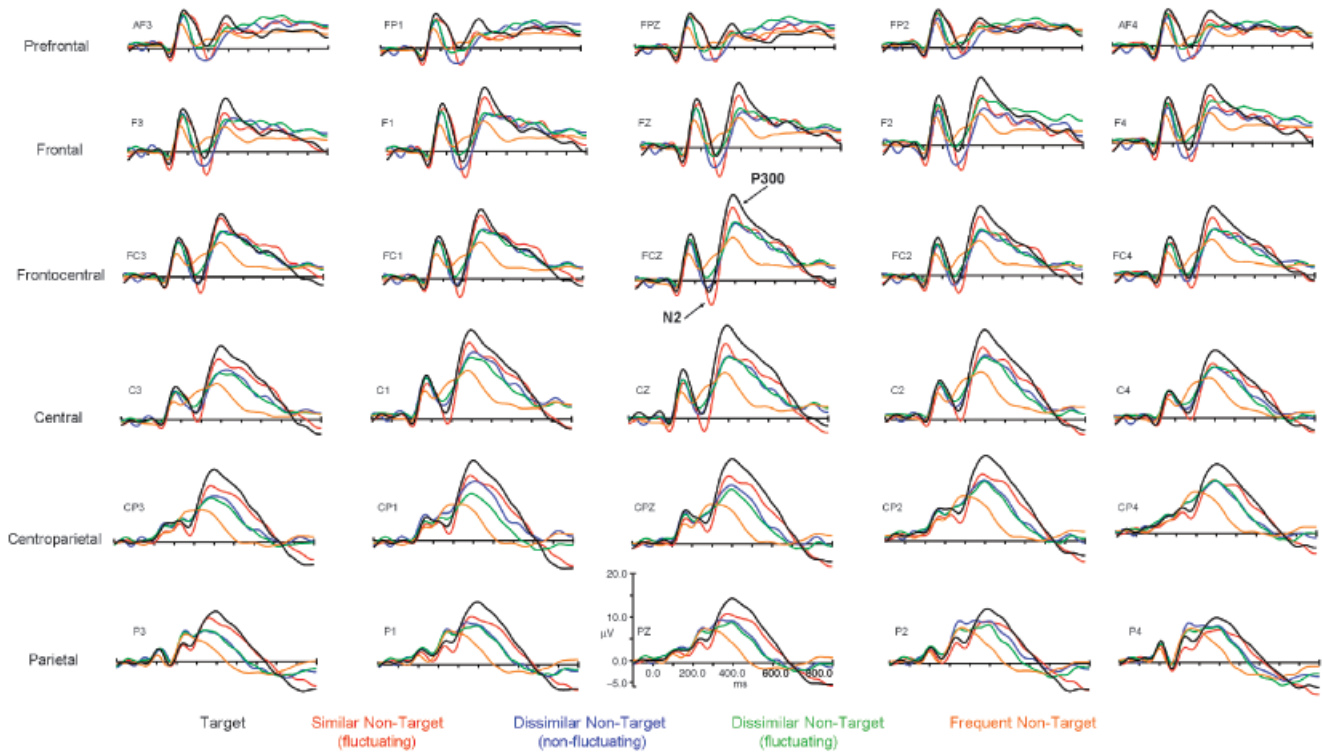
*Similar nontargets (fluctuating) versus dissimilar nontargets (fluctuating).* Strongly supporting the perceptual-overlap hypothesis, larger N2s emerged for similar than for dissimilar nontargets (fluctuating) at all anterior-posterior rows (see Table 2). Accordingly, a 2 (target similarity: similar versus dissimilar nontargets fluctuating)  $\times$  8 (electrode row) ANOVA yielded a significant effect of similarity,  $F(1,28) = 21.28, p < .0001, \eta_p^2 = .64$ , which was not affected by electrode row,  $F < 1.20, n.s.$  This effect was significant,  $p < .01$ , at the rows centered at FZ, FCZ, and CZ and was of marginal significance,  $p < .07$ , at the rows centered at FPZ, CPZ, PZ, and OZ.

*Similar nontargets (fluctuating) versus targets.* Analyses of the N2 responses to the two classes of stimuli of highest target relevance (i.e., targets and similar nontargets fluctuating; see Figure 1), a 2 (target status: targets vs. similar nontargets fluctuating)  $\times$  8 (electrode row) ANOVA yielded a significant main effect of electrode row,  $F(7,84) = 9.26, p < .005, \eta_p^2 = .44$ . More importantly, there also was a significant Target Status  $\times$  Row interaction,  $F(7,84) = 3.19, p < .05, \eta_p^2 = .21$ . As shown in Table 2, larger N2 effects emerged for the similar nontargets than for

**Table 1.** Average Response Times (in Milliseconds) and Proportions of Correct Responses on a Target-Detection Task

Stimulus	Response time	Proportion correct
Target	436.58 (42.00)	.905 (.089)
Similar nontarget (fluctuating)	446.08 (55.73)	.954 (.035)
Dissimilar nontarget (nonfluctuating)	345.26 (39.91)	.992 (.015)
Dissimilar nontarget (fluctuating)	336.38 (44.34)	.992 (.015)
Frequent nontarget	292.11 (30.34)	.997 (.006)

*Notes:* Standard deviations are in parentheses. High-frequency nontargets occurred with .60 probability; all other stimulus categories occurred with .10 probability.

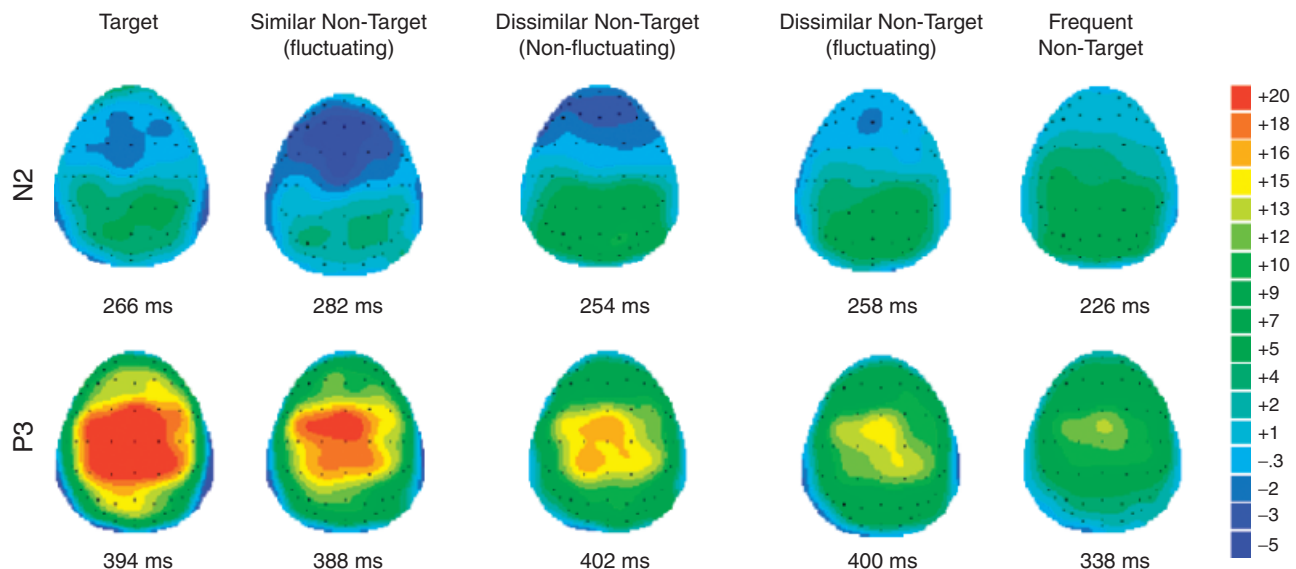


**Figure 3.** Grand-average ERPs for each stimulus category across multiple electrode sites.

the target stimuli, at anterior electrode rows. This effect was significant,  $p < .05$ , at the rows centered at FPZ, FZ, and FCZ and was of marginal significance,  $p < .07$ , at the row centered at CPZ,  $p < .09$ .

*Dissimilar nontargets (fluctuating) versus dissimilar nontargets (nonfluctuating).* To rule out the possibility that the larger N2 responses to similar nontargets fluctuating than to targets reflected a process whereby stimulus fluctuation itself (rather than similarity) increases the size of the N2, we also examined responses to the two corresponding classes of stimuli of lower

target relevance (i.e., dissimilar nontargets fluctuating and nonfluctuating; see Figure 1). In this analysis, a 2 (stimulus fluctuation: dissimilar nontargets fluctuating vs. dissimilar nontargets nonfluctuating)  $\times$  8 (electrode row) ANOVA yielded a significant main effect of electrode row,  $F(7,84) = 23.40$ ,  $p < .005$ ,  $\eta_p^2 = .66$ . More importantly, there also was a significant Fluctuation  $\times$  Row interaction,  $F(7,84) = 7.05$ ,  $p < .01$ ,  $\eta_p^2 = .37$ , in a direction *opposite* to that reported above for the comparison of responses to targets versus similar nontargets fluctuating. As shown in Table 2, significantly *smaller* N2 effects emerged in responses to the dissimilar nontargets fluctuating than to the



**Figure 4.** Sixty-four channel ERP topographical maps at time points corresponding to N2 (top panel) and P3 (bottom panel).

**Table 2.** Mean Amplitudes of N2 and P3 Responses at Eight Anterior/Posterior Electrode Locations to Five Stimulus Types that Varied in Similarity to Each Participant's Assigned Target Stimulus

Anterior/posterior electrode locations	Similar nontarget (fluctuating)	Target	Dissimilar nontarget (fluctuating)	Dissimilar nontarget (nonfluctuating)	Frequent nontarget
Averaged amplitudes of N2 responses to target and nontarget stimuli					
Prefrontal	-3.87 (1.81)	-1.13 (1.38)	-1.13 (1.31)	-4.42 (1.10)	-0.74 (0.82)
Frontal	-6.22 (1.90)	-2.86 (1.64)	-1.82 (1.37)	-5.03 (1.08)	-0.30 (0.76)
Fronto-central	-5.29 (1.81)	-2.71 (1.62)	-0.82 (1.72)	-3.05 (1.07)	1.45 (0.80)
Central	-2.02 (1.46)	0.05 (1.02)	1.97 (1.82)	-0.05 (1.22)	3.23 (0.88)
Centro-parietal	1.61 (1.05)	2.83 (0.80)	3.94 (1.49)	3.73 (0.98)	4.52 (0.85)
Parietal	2.11 (1.22)	2.64 (0.84)	4.58 (1.28)	5.69 (1.00)	4.80 (0.83)
Parieto-occipital	1.67 (1.07)	1.02 (0.92)	3.46 (0.76)	4.77 (0.90)	3.75 (0.78)
Occipital	0.61 (0.84)	0.91 (0.67)	2.62 (0.54)	3.68 (0.55)	2.35 (0.61)
Averaged amplitudes of P3 responses to target and nontarget stimuli					
Prefrontal	7.49 (1.63)	9.41 (1.64)	7.09 (0.96)	5.64 (1.29)	5.66 (1.07)
Frontal	11.12 (1.37)	14.69 (1.61)	9.45 (0.68)	8.33 (1.27)	7.11 (0.92)
Fronto-central	15.94 (1.37)	19.19 (1.27)	13.05 (1.06)	12.51 (1.51)	10.13 (0.87)
Central	17.38 (1.31)	21.04 (0.98)	14.60 (1.19)	14.70 (1.62)	12.00 (1.02)
Centro-parietal	15.79 (1.31)	19.45 (1.41)	12.77 (1.23)	14.58 (1.57)	10.49 (0.79)
Parietal	11.05 (0.76)	13.95 (0.83)	9.21 (1.06)	10.57 (0.93)	7.05 (0.66)
Parieto-occipital	7.82 (0.85)	8.85 (1.31)	6.53 (0.82)	7.02 (0.88)	4.80 (0.87)
Occipital	5.25 (0.77)	6.28 (1.44)	-4.75 (0.88)	5.35 (0.53)	3.43 (0.87)

dissimilar nontargets nonfluctuating stimuli at anterior electrode rows. This effect was significant,  $p < .05$ , at the rows centered at FPZ, FZ, and FCZ. Accordingly, follow-up reaction-time analyses showed that participants responded more slowly to the nonfluctuating dissimilar nontargets than to fluctuating dissimilar nontargets (difference  $M = 8.88$  ms,  $SD = 14.14$  ms;  $t[12] = 2.26$ ,  $p < .05$ ,  $\eta_p^2 = .09$ ).

### The P3 Component

*Targets versus similar nontargets (fluctuating).* Most important to note among the P3 effects, larger P3 effects were evoked by target than by similar nontarget stimuli at all anterior/posterior electrode rows. Accordingly, a 2 (target status: targets vs. similar nontargets fluctuating)  $\times$  8 (electrode row) ANOVA yielded a significant effect of target status,  $F(1,12) = 12.24$ ,  $p < .005$ ,  $\eta_p^2 = .51$ , which additionally was moderated by electrode row,  $F(7,84) = 2.62$ ,  $p < .05$ ,  $\eta_p^2 = .18$ . As shown in Table 2 (bottom panel), in direct contrast with the N2 results (Table 2, top panel), significantly larger P3 effects emerged for the targets than for the similar nontargets. This effect was significant,  $p < .05$ , at all anterior/posterior electrode rows except those centered at POZ and OZ. In contrast to the N2 effects between the dissimilar nontargets, stimulus fluctuation between the dissimilar nontargets showed no significant effect in the P3 time window,  $F(7,84) = 1.97$ ,  $p > .11$ .

### Target Similarity

To replicate our previous analytic approach (Azizian et al., 2006), we also compared amplitude of P3 responses to similar nontargets to the average amplitude of P3 responses to equiprobable nontarget categories (i.e., the average of responses to the nontarget and the fluctuating nontarget) across five anterior/posterior rows (those corresponding to FPZ, FZ, FCZ, CZ, and PZ), based on the average of the five central electrodes at each row (e.g., F4, F2, FZ, F1, F3). Documenting higher-amplitude P3 responses to similar nontargets, this analysis yielded a significant effect of target similarity,  $F(1,12) = 5.35$ ,  $p < .05$ ,  $\eta_p^2 = .31$ , which was not moderated by electrode row,  $F(4,84) = 1.21$ ,  $p > .30$ . The P3 similarity effect was significant,  $p < .05$ , at the

FCZ row and of marginal significance,  $p \leq .07$ , at the rows centered at FZ, CZ, and CPZ.

### Discussion

To investigate the neural processes relating perceptual similarity to action control, the current study used a novel choice RT design that required competition between two responses to several stimulus categories that varied in their perceptual overlap with one another. Consistent with classic oddball findings, a target stimulus requiring a rare response elicited an enhanced P3. Most importantly, however, similar nontarget stimuli elicited an enhanced N2 and an intermediate P3. The N2 was modulated according to the perceptual overlap between target and nontarget stimuli and appeared to reflect the strength of conflicting action tendencies. On the other hand, the P3 appeared more sensitive to the extent of cognitive processing needed for stimulus categorization. The N2 and P3 modulations were manifested independently and appeared to reflect each component's functional specialization.

### Conflict Monitoring and the N2 Component

Conflict monitoring accounts of the N2 component predict that increasing perceptual overlap should increase the size of the N2, given that overcoming incorrect responses would require greater cognitive effort. As reviewed above, however, previous work has found mixed support for this hypothesis with respect to visual stimuli (e.g., Folstein & Van Petten, 2004; Nieuwenhuis et al., 2004). The behavioral data indicated that perceptual overlap was manipulated successfully and prolonged response times were obtained for targets and similar nontargets. ERP findings showed that perceptual overlap among targets and nontargets elicited a prominent fronto-central N2, supporting interpreting the N2 as sensitive to the strength of conflicting action imperatives.

### Why More Prominent N2 Responses to Similar Nontargets than to Targets?

Also noteworthy, in the current study, the N2/P3 complex was modulated independently of response and stimulus frequency.

There is consensus in the literature that response conflict should be maximal when a low-frequency response must be executed in the context of habitual responses (e.g., Nieuwenhuis et al., 2003). In the current study, contrasting with much previous work, a larger N2 emerged when participants performed a common response (to the similar nontargets) than when they performed a rare response (to the targets). Following a general view of the N2 as sensitive to the strength of conflicting action tendencies, this interesting result suggests greater conflict (or need for response inhibition) on the similar nontargets than on the target trials. This asymmetry is consistent with the N2 perceptual-overlap hypothesis when one considers that the target stimulus, as the only stimulus in its “target” category, is perfectly representative of its category (i.e.,  $0.10/0.10 = 1.0$ ; see Figure 1). In contrast, the similar nontarget is relatively less representative of its heterogeneous “nontarget” category, in that it occurs only on a small minority of nontarget trials (i.e.,  $0.10/0.90 = 0.11$ ; see Figure 1). Accordingly, as various exemplar-based categorization models would predict, presentation of the similar nontarget should cue exemplars of the category “target” more readily than presentation of the target should cue exemplars of the category “nontarget” (e.g., Lamberts, 2000; Nosofsky & Palmeri, 1997). This asymmetry in cueing the wrong category would then lead to asymmetry in cueing the wrong response, thus creating stronger (task-inappropriate) impulses to respond “target” on the similar nontarget trials than to respond “nontarget” on the target trials. In this study, then, perceptual overlap appeared a stronger determinant of the N2 than did response frequency.

#### ***Inverse Relationship between the N2 and P3***

In many previous studies, ERPs to stimuli that require overcoming prepotent responses often have been associated with both prominent N2 and P3 components (e.g., Donkers & Van Boxtel, 2004; Nieuwenhuis et al., 2003, 2004). Extending that past work, the currently reported data demonstrated an inverse relationship between the N2 and P3 components (see Figure 3). In the present experiment, (similar nontargets) stimuli requiring a common response elicited prominent N2 and intermediate P3 components, whereas (target) stimuli requiring a rare response elicited prominent P3 and relatively smaller N2 components. Thus, whereas much evidence suggests important functional commonalities in the N2 and the P3, such as their shared sensitivity to target categorization and frequency, the current work helps confirm each component’s functional specialization.

#### ***Functional Significance of Nontarget P3s***

The P3 also was affected by perceptual similarity between target and nontarget stimuli. Similar nontargets elicited P3s that were topographically identical to those elicited by targets, but with lower amplitudes. Because similar nontargets were averaged on the basis of correct behavioral responses, these intermediate P3s cannot be attributed to false alarms in which participants mistakenly classified targetlike stimuli as targets. Moreover, the nontarget P3s cannot be reconciled in terms of stimulus expectancy or classic target effects (e.g., Duncan-Johnson & Donchin, 1977; Johnson & Donchin 1978, 1980; Squires, Squires, & Hillyard, 1975). That is, these components reflected processes that were distinct from detection of infrequent task-relevant stimuli. As shown in Figure 3, although target and nontarget P3s were similar topographically, clear distinctions can be made on

the basis of amplitude voltage and late activity. Most notably, the P3 amplitude elicited by similar nontargets was significantly larger than those elicited by the dissimilar categories. It is also worth noting that, after the peak of the P3, the electrophysiological responses to targets and similar nontargets showed a similar pattern in baseline return, which was more prolonged than that for dissimilar categories.

Previous research supports that target P3s are independent of nontarget configuration, whereas nontargets are directly influenced by the stimulus context (Katayama & Polich, 1998). Support for this hypothesis comes from a series of studies using the classic three-stimulus oddball paradigm (e.g., Hagen, Gatherwright, Lopez, Polich, 2006). A major limitation of this approach is that comparisons are confined to two classes of stimuli: infrequent targets and (similar or dissimilar) nontargets. Hence, little is known about the effects of stimulus context on infrequent nontargets that vary systematically according to their targetlike characteristics. Furthermore, in the three-stimulus oddball paradigms, participants respond only to target stimuli, providing indirect assessment for the behavioral implications of nontarget classification. In the present study, these issues were addressed systematically in a choice RT paradigm in which participants categorized stimuli on the basis of their perceptual characteristics. The results demonstrate that the P3 amplitude may be utilized as a good physiological index of similarity between target and nontarget stimuli.

An important question that remains to be addressed, then, is the functional significance of nontarget P3s. There is both empirical and theoretical support that the P3 amplitude is sensitive to the amount of attention or cognitive effort allocated to a task (for a review, see Kok, 2001). In the present study, both the behavioral performance and the ERP data suggest that cognitive effort for classification was strongly affected by perceptual overlap between targets and nontargets. Response times for targets and similar nontargets were longer than for dissimilar categories, suggesting that target and similar nontarget classification required more effort than dissimilar categories. These effects emerged independent of response and stimulus frequency. The ERP data were consistent with the behavioral pattern and revealed that P3 amplitudes were greater for targets and similar nontargets than for dissimilar categories. Stimuli that are perceptually distinct from targets are easily classified without the need for extensive cognitive computations (e.g., Nosofsky & Palmeri, 1997). Accordingly, we have suggested that P3 amplitude can be interpreted as an index of the extent of cognitive processing needed for categorizing stimuli varying in similarity to the target (Azizian et al., 2006). Findings from the current study showed that stimuli that require more extensive categorical processing produce more prominent P3s. In contrast, dissimilar stimuli that are easily classified as nontargets require less cognitive processing and produce smaller late positivity. Thus, the magnitude of this positivity appears sensitive to the extent of cognitive processing necessary for classification.

#### ***Summary and Conclusions***

Event-related potentials were used to investigate neural processes relating perceptual similarity to action control. Perceptual similarity between visual target and nontarget categories affected reaction times and modulated the N2/P3 ERP components. Among targets, dissimilar nontargets, and similar nontargets, the latter reliably elicited the most prominent N2 responses. These



findings are consistent with the view that stimuli that cue conflicting responses augment the size of the N2 component. The most prominent P3 responses, in contrast, were elicited

by targets. This divergence of N2 and P3 response patterns substantiates these distinct electrophysiological signals' associations with distinct cognitive processes.

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