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The visual N1 component as an index of a discrimination process

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Abstract

Many previous studies have demonstrated that the visual N1 component is larger for attended-location stimuli than for unattended-location stimuli. This difference is observed typically only for tasks involving a discrimination of the attended-location stimuli, suggesting that the N1 wave reflects a discrimination process that is applied to the attended location. The present study tested this hypothesis by examining the N1 component elicited by attended stimuli under conditions that either required or did not require the subject to perform a discrimination. Specifically, the N1 elicited by foveal stimuli during choice-reaction time (RT) tasks was compared with the N1 elicited by identical stimuli during simple-RT tasks. In three experiments, a larger posterior N1 was observed in choice-RT tasks than in simple-RT tasks, even when several potential confounds were eliminated (e.g., arousal and motor preparation). This N1 discrimination effect was observed even when no motor response was required and was present for both color- and form-based discriminations. Moreover, this discrimination effect was equally large for easy and difficult discriminations, arguing against a simple resource-based explanation of the present results. Instead, the results of this study are consistent with the hypothesis that the visual N1 component reflects the operation of a discrimination process within the focus of attention.

Descriptors: Selective attention, Visual discrimination, Event-related potential, N1

Many studies of visual-spatial selective attention have found that attended-location stimuli elicit larger P1 and N1 components of the event-related potential (ERP) than unattended-location stimuli (for a review, see Magun, 1995). These amplitude modulations, which are termed the *P1 and N1 attention effects,* were originally interpreted as evidence that attention operates as a sensory gain control, with a single early change in gain being propagated to each subsequent stage of processing (Eason, Harter, & White, 1969; Van Voorhis & Hillyard, 1977). Further studies, however, have suggested that the P1 and N1 attention effects can be dissociated and reflect qualitatively different mechanisms of attention (Luck et al., 1990). Specifically, P1 attention effects have been observed in the absence of N1 attention effects and vice versa, which suggests that these effects reflect different attentional mechanisms.

The information-processing correlates of the sensory-evoked visual P1 and N1 components are not well understood, which makes it difficult to characterize the specific attentional mechanisms reflected by the P1 and N1 attention effects. The goal of the present study was to address this deficiency in our knowledge by examining the nature of the visual N1 component without the added complication of spatial attention manipulations. Specifically, this study tested the hypothesis that the N1[1] component reflects, at least in part, the operation of a discriminative process (Luck, 1995). This proposal is based on two primary findings. First, the N1 attention effect appears to reflect a relatively pure enhancement of attended-location stimuli rather than a combination of attended-location enhancement and ignored-location suppression. Specifically, N1 amplitude is greater for attended-location stimuli compared with stimuli presented under neutral or distributed-attention conditions, but there is no suppression of N1 amplitude for stimuli presented outside the focus of attention compared to neutral baseline conditions (Luck & Hillyard, 1995; Luck et al., 1994). Second, the N1 attention effect appears to be found only when subjects are required to make a discrimination, and it is

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[1] In this article, we use the label "N1" to refer to the visual N1 component, as opposed to the auditory N1 component. Like the auditory N1, which has multiple subcomponents (Näätänen & Picton, 1987), the visual N1 also appears to have multiple subcomponents (Luck, 1995). The effects described here probably apply only to a subset of these subcomponents and may not even consist of a modulation of an exogenous N1 subcomponent. Thus, we are using the term "N1" purely descriptively to denote an effect in the latency range of the first major negative component.

absent when subjects must merely detect the presence of a stimulus (Mangun & Hillyard, 1991)[2].

Based on the general conditions necessary for observing the N1 attention effect, we propose that the visual N1 component (or one subcomponent of the N1 complex) reflects a discriminative process[3] that is applied to a restricted area of visual space. However, it is not clear precisely what type of discrimination process the N1 reflects. In addition, most previous studies of the visual N1 component and discriminative processing have been designed to examine spatial attention and have not been directly focused on characterizing the N1 component itself. The present study was designed to address this specific issue.

To examine the proposed relationship between the N1 wave and discrimination, we used a paradigm that was developed by Ritter and his colleagues to examine the electrophysiological correlates of discriminative processing (Ritter, Simson, & Vaughan, 1983, 1988; Ritter, Simson, Vaughan, & Macht, 1982). These experiments did not examine the role of spatial attention, but instead used foveal stimuli and manipulated whether or not subjects were required to make a discrimination about the stimuli. This was accomplished by comparing a choice-reaction time (RT) task, in which subjects pressed one of two buttons depending on the form of the stimulus, with a simple-RT task, in which subjects pressed a single button upon detecting any stimulus. In several experiments, Ritter et al. (1983) found that ERP activity was more negative from approximately 150 to 400 ms in the choice-RT condition than in the simple-RT condition. They proposed that this difference consisted of two distinct negative-going components: an initial component they named the *NA wave* and a later component that was sensitive to stimulus probability and was therefore identified as the N2 wave (Näätänen, 1982). As the following experiments indicate, the posterior portion of the NA wave occurs in the N1 latency range and is similar to the attention effects observed in spatial attention experiments, and we will therefore refer to it as the *N1 discrimination effect*. Note, however, that this term is not meant to imply that the effect consists of a modulation of an exogenously evoked subcomponent of the N1 complex, but merely that this effect occurs in the latency range of the N1 component.

Ritter et al. (1983) proposed that the N1 discrimination effect reflects the operation of a pattern recognition mechanism, which is similar to our own proposal concerning the N1 attention effect. However, N1 attention effects have been observed in color and luminance discrimination experiments as well as form discrimination experiments (Heinze, Luck, Mangun, & Hillyard, 1990; Luck et al., 1994; Mangun & Hillyard, 1991), and we therefore hypothesize that the N1 discrimination effect reflects a more general discrimination mechanism. Experiment 1 of the present study assessed these alternative hypotheses by using a variant of the Ritter paradigm, comparing a simple-RT condition with both a form-discrimination choice-RT condition and a color-discrimination choice-RT condition. We predicted that an equally larger N1 wave would be observed in both the color and form choice-RT conditions relative to the simple-RT condition, which would indicate that this effect is not specific to pattern recognition.

The paradigm used by Ritter and colleagues provides a straightforward and elegant means of examining the relationship between the N1 wave and discriminative processing. This approach uses the simple logic that the primary difference between a simple-RT task and a choice-RT task is the necessity of a discrimination, and any differences in the ERPs between these two conditions should reflect the neural manifestation of this discrimination process. However, the comparison of simple- and choice-RT tasks assumes that these tasks differ only in terms of the addition of a discrimination process in the choice-RT task, but this assumption may not be valid. For example, simple-RT tasks are typically easier than choice-RT tasks, which may have resulted in less overall attention and a decreased state of arousal. Moreover, the experiments of Ritter et al. (1983, 1988) may have further increased the difference in difficulty between the two tasks by using a fixed interval between stimulus presentations and no catch trials. As a result of this fixed stimulation rate, subjects in the simple-RT conditions were not required to engage in the task any further than simply responding at a constant rate. Therefore, the N1 discrimination effect found by Ritter et al. (1983, 1988) may have been simply due to comparing conditions in which subjects were in different global states of arousal and attention, with a larger N1 wave elicited in the choice-RT condition than in the simple-RT condition because of arousal and attention rather than a specific discriminative process. In the present study, we used a variable interstimulus interval and occasional catch trials to reduce anticipatory responses and to ensure that subjects were in an attentive state and engaged in some minimal stimulus processing in the simple-RT conditions. In addition, to further address the possible effects of arousal differences, we compared a highly speed-stressed simple-RT condition with a normal simple-RT condition. If the N1 discrimination effect reflects an increase in arousal, we would expect to observe a larger N1 for the speed-stressed simple-RT condition than for the normal simple-RT condition.

A second possible difference between these two tasks stems from the fact that subjects have faster response times in the simple-RT conditions than the choice-RT conditions. A disparity in RTs could be a potential confound because response-related ERP components may overlap with the early stimulus-related components, and a difference in the timing of the response-related components between the simple- and choice-RT conditions may have created the appearance of a difference in the stimulus-related components in these conditions. Consistent with this possibility, the effect described by Ritter et al. (1983, 1988) was maximal at central midline electrode sites, which lie directly above motor areas of the cortex. Also, given that RTs were extremely fast in the simple-RT condition, it is plausible that motor preparatory potentials began in the N1 latency range. Thus, it is possible that the N1 discrimination effect is at least partially due to differences in the timing of overlapping motor preparation potentials in the simple- and choice-RT conditions. This possibility was addressed in Experiment 2, in which motor potentials were minimized by using silent counting tasks rather than RT tasks.

A third difference between simple- and choice-RT conditions is that choice-RT conditions typically require a greater allocation of

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[2] However, there is one study in which an N1 attention effect was found for a task that did not require a discrimination. Luck et al. (1994) found an N1 attention effect for a near-threshold luminance detection task, in which subjects reported the presence or absence of a brief, small dot that was immediately followed by a large pattern mask. Although this result would appear to contradict the claim that the N1 attention effect occurs only in discrimination tasks and not in detection tasks, it is actually an ambiguous case because the subjects may have been performing a discrimination between dot-plus-mask and mask-alone stimuli.

[3] We use the term "discrimination" to refer broadly to the process of differentiating between two or more types of stimuli. However, our use of this term does not imply any specific aspect of this process (i.e., comparison process, retrieval from memory, etc.). This definition is intentionally vague because it is not presently clear what aspect of this process the N1 attention effect reflects. Therefore, the goal of the present study is to argue simply for the existence of a general discrimination process and to provide evidence that the N1 component may be a neural substrate of this process.

perceptual processing resources than simple-RT conditions (see Lavie, 1995; Lavie & Tsal, 1994). That is, the difference in general perceptual load, and not specific requirements of a discrimination, may underlie the larger N1 wave observed in the choice-RT conditions. This possibility was tested in Experiment 3.

EXPERIMENT 1

In this experiment, we addressed several issues concerning the N1 discrimination effect. First, we addressed the generality of the discrimination process reflected by the N1 effect by comparing a color-discrimination choice-RT task with a form-discrimination choice-RT task. Second, we examined the possibility of differential arousal by comparing a normal simple-RT task with a speed-stressed simple-RT task. Finally, we used two separate offline signal-processing techniques to minimize the problem of overlapping motor-related ERP components. The first method was simply to attenuate the very low frequencies in the waveform by means of a digital high-pass filter. Preparatory potentials, such as the contingent negative variation and the readiness potential tend to be sustained low-frequency shifts, and overlapping late waves from previous trials also tend to be low frequency deflections (McAdam & Rubin, 1971; Papakostopoulos & Fenelon, 1975); these overlapping waves can therefore be attenuated by use of a high-pass filter. The second procedure estimated and removed the overlapping motor-related potentials by using the Adjar (adjacent response) filter described by Woldorff (1993). The Adjar filter is an iterative procedure that can be used to eliminate motor-related activity by convolving the observed ERP waveform for the motor response (measured in response-locked averages) with the probability distribution of the interval between the onset of the stimulus array and the motor response. This estimate of the motor activity can then be subtracted from the observed ERP waveform for the stimulus array. After the estimated motor activity has been subtracted from each ERP waveform, this procedure is iterated using the new estimates of the ERP waveforms. Because the new ERP waveform estimates are less contaminated by motor activity, improved estimates of the motor activity are produced in subsequent iterations, leading to improved estimates of the true stimulus-elicited ERP waveforms. In the present study, 10 iterations of this procedure were sufficient to remove all signs of motor activity from the waveforms. Together, these two techniques (high-pass filtering and Adjar) should minimize any differential overlap and motor activity between the simple-RT and choice-RT conditions.

Methods

Participants

Twelve college student volunteers between 18 and 30 years of age (5 men; 3 left-handed) were either paid or received course credit for their participation in this experiment. All subjects had normal or corrected-to-normal acuity, reported normal color vision, and had no history of neurological disorders.

Stimuli

As illustrated in Figure 1, the stimuli in this experiment were five-letter arrays presented at the center of a video monitor at a viewing distance of 70 cm. The letters in a given array were randomly selected with replacement from a set of six letters (N, W, M, Z, O, and T). The letters were presented in a horizontal row, centered along the horizontal meridian. Each letter subtended 0.5° × 0.5°, and the entire array spanned 3°. On every trial, each letter was randomly assigned a color from the set of blue (CIE-UCS coordinates: $u' = .165$, $v' = .295$), gray ($u' = .217$, $v' = .449$), green ($u' = .145$, $v' = .549$), yellow ($u' = .257$, $v' = .545$), purple ($u' = .243$, $v' = .251$), and red ($u' = .449$, $v' = .519$). All of the colors were closely matched for luminance (ranging from 17.01 to 17.83 cd/m^2) and were presented on a dark gray background (0.27 cd/m^2). Each array was presented for 100 ms, and the interval between successive stimulus onsets (stimulus onset asynchrony, SOA) ranged from 1,300 to 1,500 ms. On catch trials, a 100-ms stimulus-free interval was presented in place of a letter array.

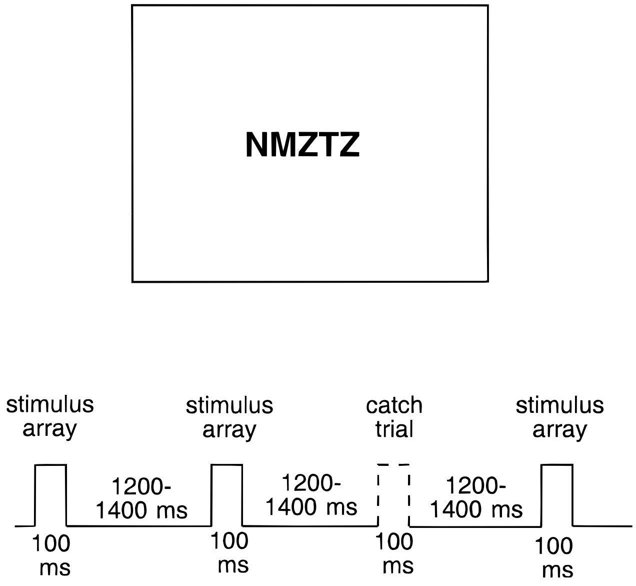

Figure 1. Example stimulus array and timing for Experiment 1. Each array subtended 3°, and the color of each letter within the array was randomly assigned. Stimulus arrays were presented for a duration of 100 ms, followed by a variable interstimulus interval of 1,200–1,400 ms. Catch trials consisted of a 100-ms blank interval in the place of a letter array.

Procedure

Identical stimuli were used in four different task conditions. In two of the conditions, participants performed simple-RT tasks, in which they were required to press a button at the onset of each letter array, regardless of what letters or colors were presented within the array. In one of the simple-RT conditions, the participants were required to respond as quickly as possible upon detecting a stimulus. This condition was denoted sRT-normal and corresponds to the simple-RT condition used by Ritter et al. (1983). In the other simple-RT condition, denoted sRT-fast, even greater stress was given to the subjects to respond quickly. Specifically, the subjects were given feedback at the end of each sRT-fast trial block indicating their mean RT for that block and stating that they must respond even faster in the next sRT-fast block.

The other two conditions involved choice-RT tasks, in which subjects looked for a specified target letter or target color in each array. In the cRT-form condition, subjects were instructed to press one button if a target letter (the letter T) was present in an array and to press a second button if the target letter was absent. In the cRT-color condition, subjects were required to press one button if a target color (red) was present in an array and to press a second button if the target color was absent. The letter "T" was present in 8% of the arrays and the color red was present in 8% of the arrays.

Any of the five letters in an array could be red or a "T." As in the sRT conditions, subjects were asked to respond as quickly as possible, but they were not given feedback concerning their RTs.

Subjects participated in a single session consisting of 12 trial blocks, with three blocks in each of the four conditions. Each block consisted of 24 color-target trials, 24 form-target trials, 24 catch trials, and 216 target-absent trials. The order of the blocks varied randomly across subjects. Subjects responded using the index fingers of each hand in the choice-RT conditions and with the index finger of one hand in the simple-RT conditions. The response-hand mapping was counterbalanced across subjects.

Recording and Analysis

The EEG was recorded from tin electrodes mounted in an elastic cap, located at standard left- and right-hemisphere positions over frontal, central, parietal, occipital, and temporal areas (International 10/20 System sites F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, T3, T4, T5, T6, O1, and O2). Two nonstandard sites were also used: OL (halfway between O1 and T5) and OR (halfway between O2 and T6). These sites were referenced to the right mastoid during the recording session and then were re-referenced offline to the algebraic average of the left and right mastoids. The horizontal electrooculogram (EOG) was recorded as the voltage between electrodes placed 1 cm to the left and right of the external canthi to measure eye movements, and the vertical EOG was recorded from an electrode beneath the left eye, referenced to the right mastoid, to detect blinks. Trials containing these artifacts were excluded from the averaged ERP waveforms. EOG artifacts led to the rejection of an average of 18% (and a maximum of 23%) of trials in this experiment. The EEG and EOG were amplified by an SA Instrumentation amplifier with a bandpass of 0.01–80 Hz, digitized at 250 Hz by a PC-compatible computer, and averaged off-line.

Because the visual N1 component has separable anterior and posterior subcomponents with different latencies (e.g., Luck, 1995), the N1 was measured separately for anterosuperior (F3, Fz, F4, C3, Cz, C4) and inferoposterior (O1, O2, OL, OR, T5, T6) sites. N1 amplitude was quantified as the mean amplitude from 75 to 125 ms for the anterosuperior sites and as the mean amplitude from 140 to 180 ms for the inferoposterior sites. In addition to finding a difference between simple- and choice-RT tasks in the N1 latency range, Ritter et al. (1983, 1988) also found that this difference continued into the latency range of the posterior N2 component. In the present study, the posterior N2 component was measured as the mean amplitude from 220 to 270 ms at inferoposterior sites. Analysis of variance (ANOVA) was used for all statistical tests, adjusted with the Greenhouse–Geisser epsilon correction for nonsphericity (Jennings & Wood, 1976). A separate repeated-measures ANOVA was performed at each set of electrode sites with two factors, task condition and electrode location. The ERP waveforms were time-locked to the onset of the array, using the average voltage during the 200 ms before stimulus onset as a baseline. All RT and ERP results from the two sRT conditions excluded trials containing the color and form targets, thus making it possible to compare them with the nontarget cRT trials. Moreover, to minimize late-component overlap from preceding trials, trials that were preceded by a target-present trial were also excluded from the ERP averages.

Results

Behavior

Accuracy and mean RTs for each condition are shown in Table 1. Accuracy for the task was generally high, and although accuracy tended to be slightly greater in the simple-RT conditions, there were no significant differences in accuracy across conditions, $F < 1$. Overall, the simple-RT responses were faster than the choice-RT responses, $F(3,11) = 59.5$, $p < .01$, $\epsilon = 0.63$. Subsequent pairwise comparisons revealed that the sRT-fast responses were significantly faster than the sRT-normal responses, $F(1,11) = 20.03$, $p < .001$, and that the cRT-form and cRT-color RTs were not significantly different from each other, $F(1,11) = 2.17$, $p > .15$.

Table 1. *Mean Accuracy and RT for Each Condition in Experiment 1*

Condition	% Correct	Target RT	Nontarget or simple RT
cRT-color	96	471 (13)	378 (7)
cRT-form	96	503 (15)	397 (15)
sRT-normal	99	*na*	292 (18)
sRT-fast	98	*na*	223 (7)

RT = reaction time; cRT = choice-RT; sRT = simple RT.
SEM in parentheses.

Variability in the timing of psychological processes may have substantial effects on averaged ERP waveforms, and the means and standard errors shown in Table 1 do not adequately describe the variability in RT. Figure 2 therefore shows the RT probability distributions for each condition. As is typically observed, these distributions were right skewed. In addition, this figure shows that the difference in means between the simple and choice-RT conditions was large relative to the width of the RT distributions, with a significant proportion of RTs occurring within 200 ms of stimulus onset in the sRT conditions.

Electrophysiology

Overview. In the first set of analyses, we will describe comparisons of the cRT-form, cRT-color, and sRT-normal conditions, focusing on the ERP waveforms elicited by trials in which neither the form-target nor the color-target was present. The second set of analyses will compare the sRT-normal and sRT-fast conditions. The final set of analyses will compare the elicited activity from target-present trials with target-absent trials within the two cRT conditions.

Target-absent trials. Figure 3 displays the grand-average ERP waveforms for target-absent trials in the cRT-form, cRT-color, and sRT-normal conditions. At the inferoposterior electrode sites (O1, O2, OL, OR, T5, T6), the waveforms consisted of an initial positive deflection peaking around 100 ms (P1), followed by a large negative deflection peaking around 165 ms (N1). The posterior N1 peak was considerably larger in the two cRT conditions than in the sRT-normal condition, $F(2,22) = 26.37$, $p < .001$, $\epsilon = 0.65$. However, the N1 component appeared to be similar for the cRT-form and cRT-color conditions, and a subsequent pairwise comparison indicated that the form and color conditions were not significantly different from each other, $F < 1$.

At the anterosuperior electrodes (F3, Fz, F4, C3, Cz, C4), the anterior N1 wave peaked around 100 ms. This component appeared largest at the central midline sites, yielding a significant main effect of electrode position, $F(5,55) = 5.15$, $p < .05$, $\epsilon = 0.46$. Like the posterior N1, this anterior N1 wave was larger during the cRT conditions than the sRT-normal condition, $F(2,22) = 4.55$, $p < .05$, $\epsilon = 0.85$. At some anterosuperior sites, the N1 was

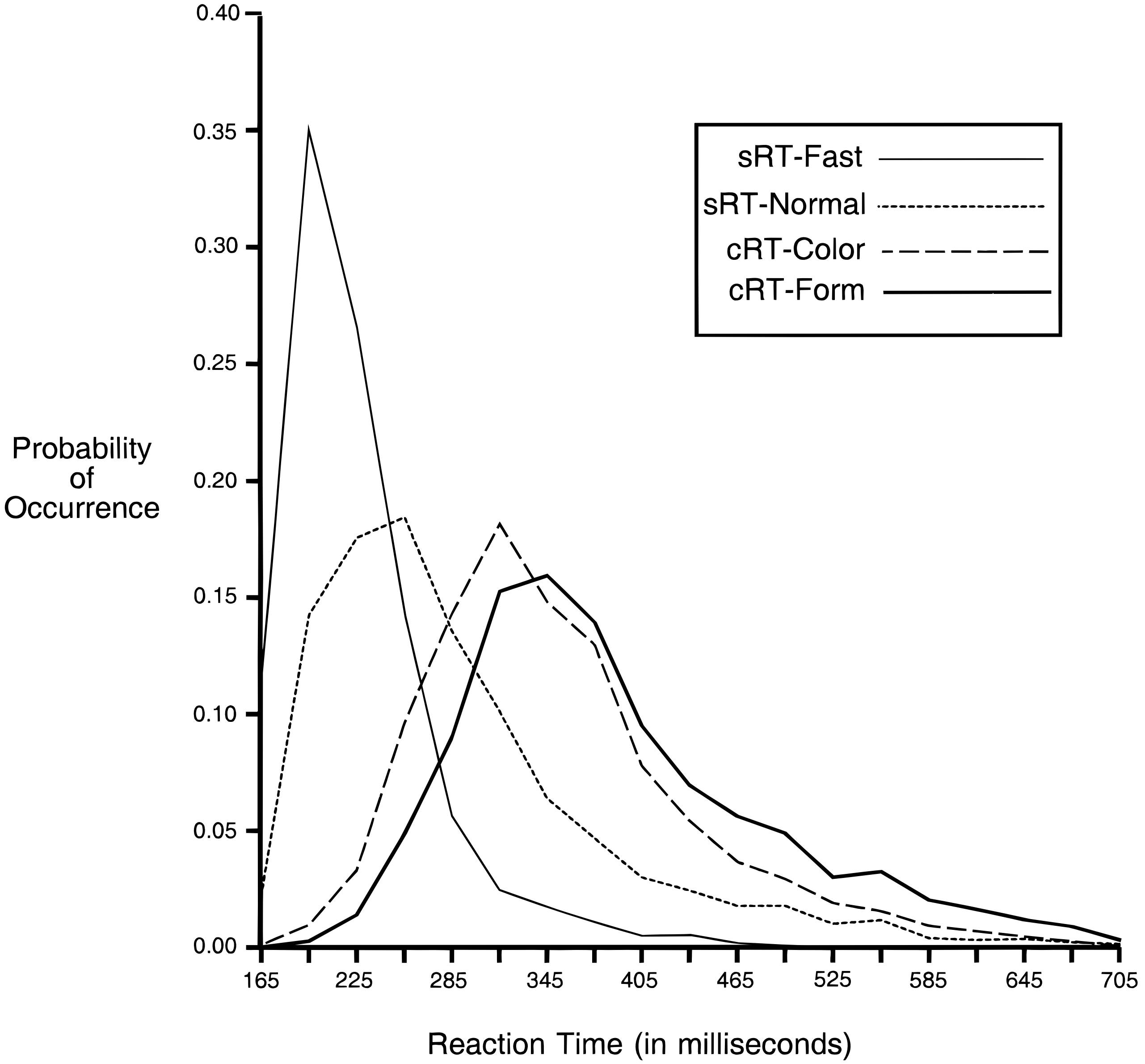

Figure 2. Probability distributions of reaction time (RT) for each condition in Experiment 1, averaged over subjects (bin width = 30 ms).

slightly larger during the cRT-form condition than for the cRT-color condition. However, the difference between these conditions was not significant in a pairwise comparison, $F < 1$.

The voltage difference between the simple- and choice-RT conditions continued beyond the N1 latency range into the N2 range at the inferoposterior electrode sites, $F(2,22) = 13.04$, $p < .01$, $\epsilon = 0.64$. However, there was no difference between the cRT-form and cRT-color conditions at inferoposterior sites in the N2 latency range, $F < 1$.

High-pass and Adjar filtering. As discussed above, the comparison between the sRT and cRT conditions may be contaminated by overlapping activity from the previous trial and by motor preparatory activity from the current trial. Indeed, there was a negative-going trend in the prestimulus interval, especially at the anterosuperior sites, and the difference between the sRT and cRT trials began as early as 0 ms at these sites (see Figure 3). To minimize this potential overlap, we first applied a digital high-pass filter with a 50% amplitude cutoff at 2 Hz.[4] We then applied 10 iterations of the Adjar filter algorithm. The results of these procedures are illustrated in Figure 4. Both the high-pass and Adjar filters significantly reduced the anterosuperior negativity that preceded the onset of the stimulus, and the amplitude of the anterior N1 wave. In addition, the size of the N1 discrimination effect at anterosuperior electrode sites was attenuated greatly, although this effect was still significant after both filtering techniques ($p < .05$). The effects of filtering were much smaller at the inferoposterior

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[4] This high-pass filtering procedure was achieved by convolving the ERP waveforms with the right half of a Gaussian impulse response function with a standard deviation of 60 ms.

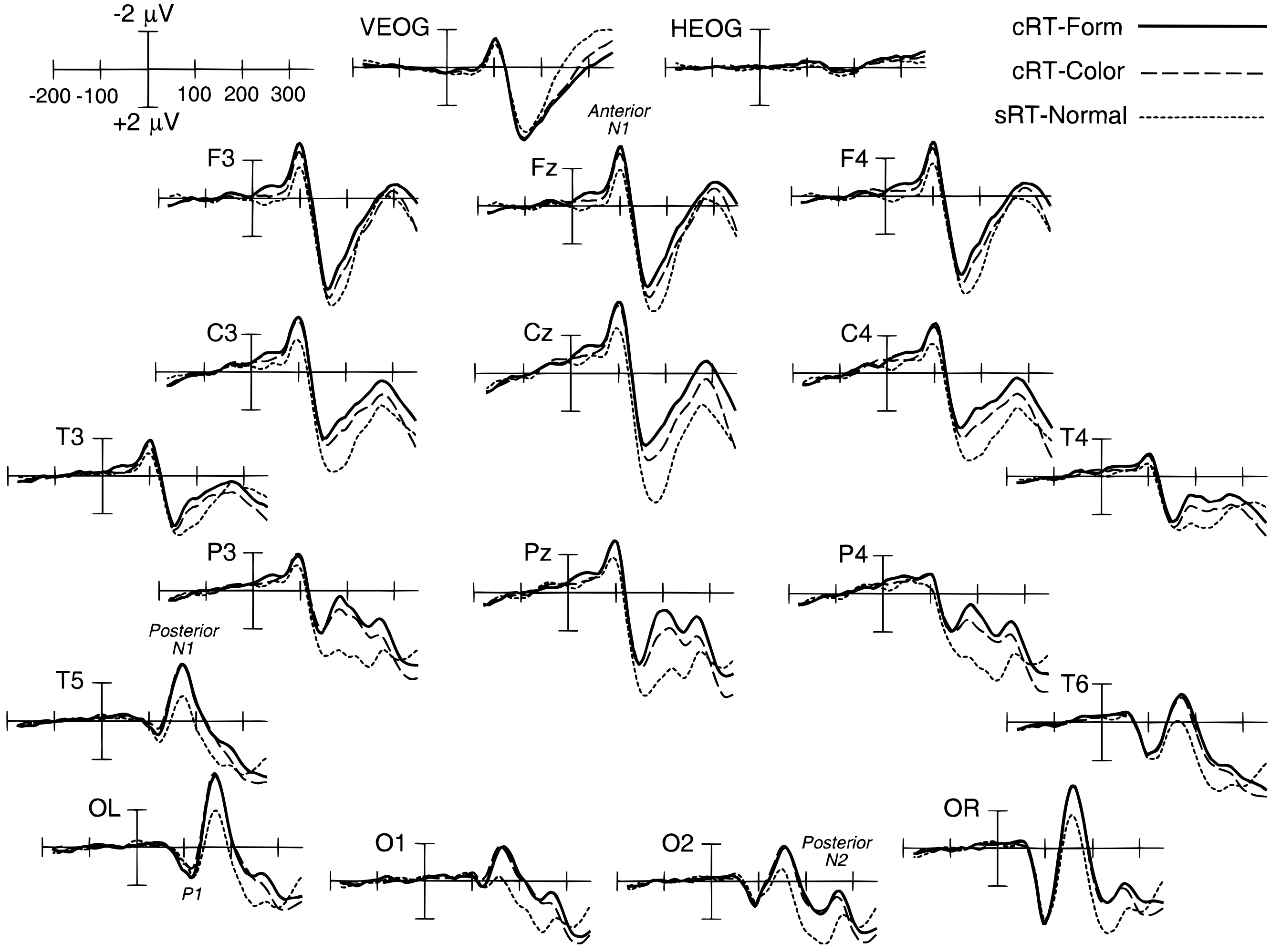

Figure 3. Grand-average event-related potential (ERP) waveforms elicited by target-absent stimuli in the choice reaction time (cRT)-form, cRT-color, and simple-RT (sRT)-normal conditions of Experiment 1. Note that negative voltage values are plotted upwards. In this and all subsequent figures, the ERP waveforms were digitally low-pass filtered by convolving the ERP waveforms with a Gaussian impulse response function (*SD* 6 ms, 50% amplitude cutoff at 30 Hz).

electrode sites, where the N1 discrimination effect was reduced only slightly and was still highly significant after both filtering techniques ($p <.01$). Filtering also greatly attenuated the later posterior N2 effect, rendering it nonsignificant ($p > .25$).

Arousal. Grand-average ERP waveforms comparing the two sRT conditions are shown in Figure 5. At inferoposterior sites, the ERPs were more positive in the sRT-fast condition than in the sRT-normal condition, beginning in the latency range of the P1 wave, and continuing for several hundred milliseconds. The statistical significance of the early portion of the effect was confirmed with an ANOVA on the P1 wave (80–120 ms), $F(1,11) = 9.92$, $p < .01$.The continuation of this effect into the N1 latency range led to a smaller posterior N1 for the sRT-fast condition than for the sRT-normal condition, $F(1,11) = 16.48$, $p < .01$. At a few anterosuperior sites, the reverse pattern was found, with a slightly larger N1 in the sRT-fast condition than in the sRT-normal condition, but this effect did not approach significance ($F < 1$). During the N2 latency range, a greater negativity was elicited in the sRT-normal condition than in the sRT-fast condition at inferoposterior sites, $F(1,11) = 21.87$, $p < .001$.

Target-present trials. Target-present stimuli[5] elicited a slightly larger N1 wave than target-absent stimuli at all sites, but this effect was not significant at either the inferoposterior sites, $F(1,11) = 1.31$, $p = .28$, or the anterosuperior sites, $F < 1$. There was, however, a significantly larger negativity for target-present than for target-absent trials in the N2 latency range at inferoposterior sites, $F(1,11) = 12.11$, $p < .01$.

Discussion

As in the study of Ritter et al. (1983), we observed a larger N1 wave for choice-RT tasks than for a simple-RT task. However, there was no difference in N1 amplitude between the color and form discrimination tasks, which supports the hypothesis that the

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[5] To allow the comparison of the same physical stimuli, form-target trials from the cRT-form condition were averaged with color-target trials from the cRT-color condition, and this target-present activity was compared with target-absent activity, computed as the average of color-target trials from the cRT-form condition and form-target trials from the cRT-color condition.

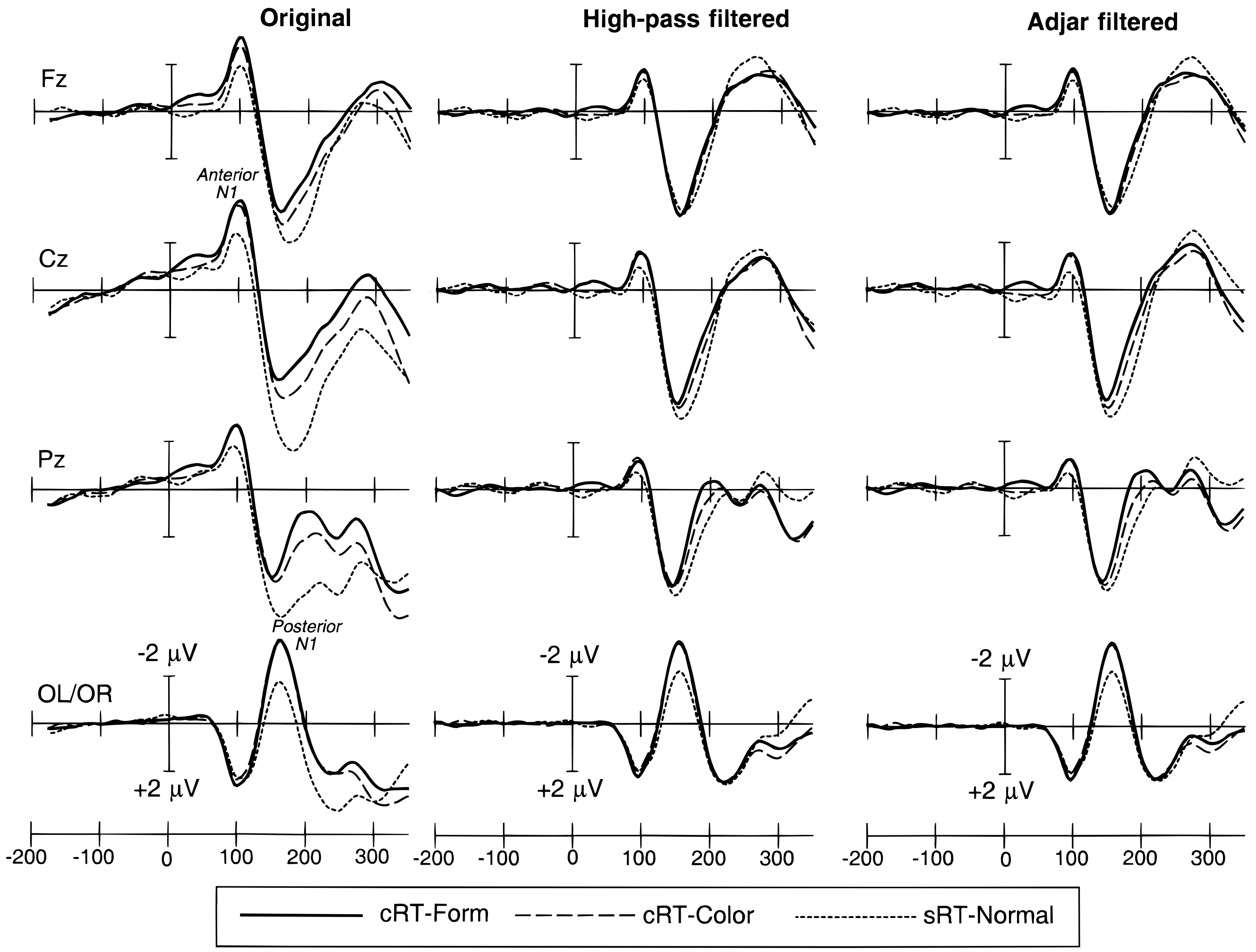

Figure 4. Event-related potential (ERP) waveforms from Experiment 1, displayed for selected sites (including an average of activity at two lateral occipital sites [OL/OR]). The first column shows the waveforms prior to any filtering of overlap or motor activity. The second column shows the same waveforms after being high-pass filtered. The third column shows the waveforms after 10 iterations of the Adjar filter procedure.

N1 discrimination effect reflects a generalized discrimination process rather than a specific pattern recognition process. In addition, the posterior N1 wave in the speed-stressed simple-RT condition was smaller than that in the normal simple-RT condition. This result indicates that the N1 discrimination effect cannot be explained by greater arousal for choice-RT tasks than for simple-RT tasks, because a direct manipulation of arousal led to the opposite effect. Moreover, increased arousal was found to lead to a larger P1 wave, but P1 amplitude was equal in the standard simple-RT and choice-RT conditions.

The primary difference between the choice-RT and simple-RT conditions was the requirement of a discrimination, and the difference in N1 amplitude between these conditions is therefore likely to reflect discriminative processing. However, one additional difference between the conditions is that the RTs for the simple-RT conditions were significantly faster than those for the choice-RT conditions (see Figure 2). Consequently, the difference in amplitude between the simple- and choice-RT conditions may in part reflect motor-related processes. Moreover, a large number of responses in the simple-RT conditions occurred within 200 ms after stimulus presentation, making it plausible that premotor activity could have influenced ERP activity in the time range of the N1 wave. In addition, the waveforms in the simple- and choice-RT conditions may have differed in terms of the activity preceding each stimulus, due to overlap from the preceding trial and motor preparation. These differences may have contributed to the differences in amplitude in the N1 latency range, especially because these differences appeared to begin as early as stimulus onset.

The two filtering techniques that we applied to the waveforms in an attempt to mitigate these possible sources of overlap attenuated the size of the anterior N1 discrimination effect, but had little effect on the posterior N1 discrimination effect. This finding suggests that the anterior N1 effect is partly or entirely the result of overlapping responses and preparatory activity, whereas the posterior N1 effect is relatively uncontaminated by such activity (which is consistent with the scalp distributions usually obtained for motor activity).

Filtering techniques such as those used here may significantly distort ERP waveforms, and they are not guaranteed to selectively remove only the activity that they were intended to mitigate. For

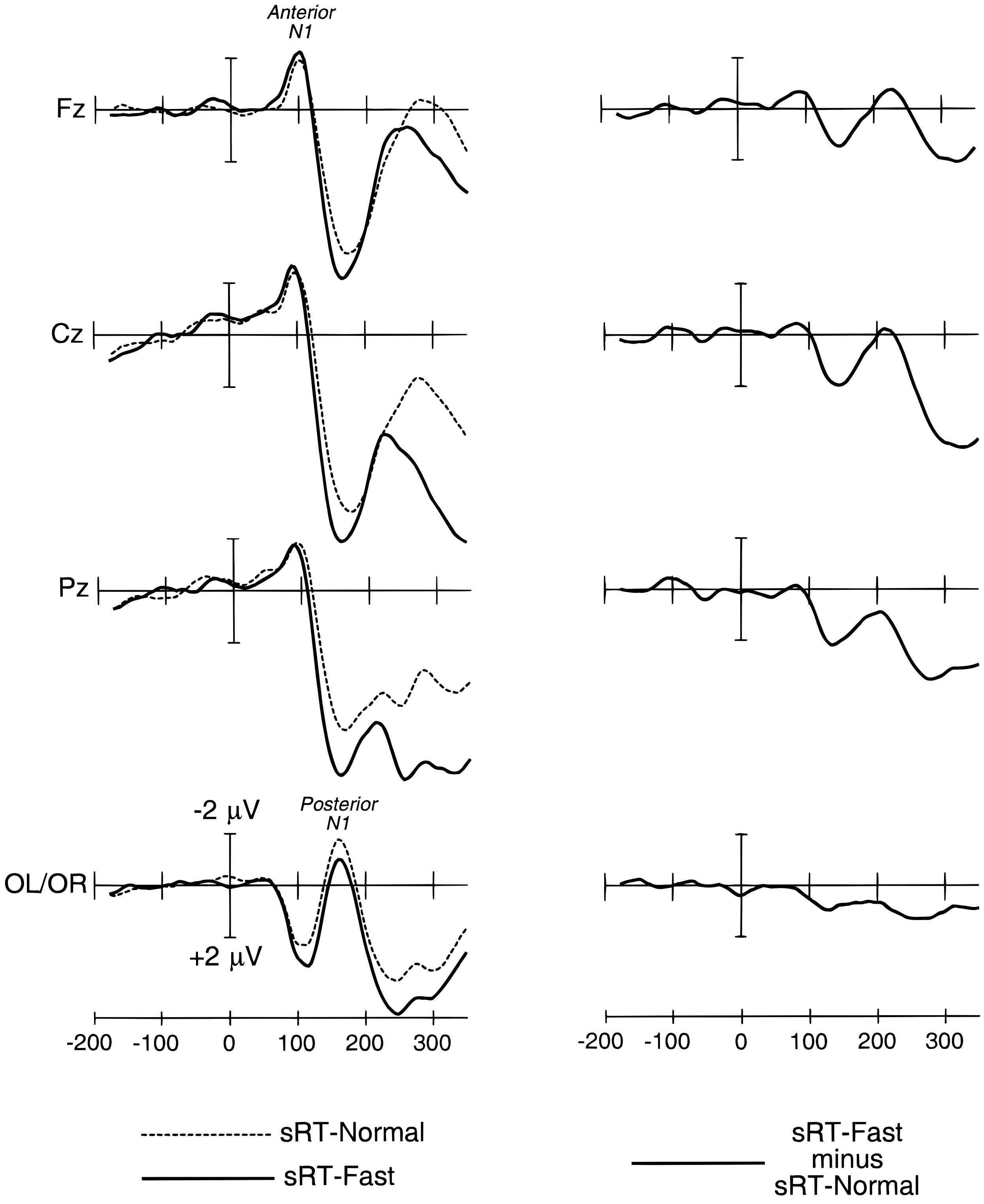

Figure 5. Event-related potential (ERP) waveforms for the simple reaction time (sRT)-normal and sRT-fast conditions in Experiment 1 (excluding trials with a color or form target), and difference waveforms constructed by subtracting activity during the sRT-normal condition from the sRT-fast condition.

example, the high-pass filter removed the very low frequencies in the waveform, and because much of the power in the N2 wave resides in a relatively low frequency range, the attenuation of the N2 effect by high-pass filtering does not necessarily indicate that the N2 effect was artifactual. Before dismissing the anterior N1 discrimination effect as an artifact, therefore, providing further evidence about the role of motor-related artifacts in the anterior and posterior N1 discrimination effects is necessary. In Experiment 2, we addressed this issue by eliminating the motor response from both the simple- and choice-RT tasks.

EXPERIMENT 2

This experiment was designed to explore directly the role of motor responses in the anterior and posterior N1 discrimination effects. Specifically, we compared the simple- and choice-RT tasks used in Experiment 1 with two tasks that were analogous but did not require any motor output. In these tasks, the subjects were instructed to count the number of stimuli presented and to report this number at the end of a long sequence of stimuli. In the counting analog of the choice-RT condition, subjects were required to count the number of color targets presented within each block of trials. In the counting analog of the simple-RT task, subjects were required to count the total number of stimuli presented within each block. These two counting tasks differ in their discriminative demands, just like the simple- and choice-RT tasks, but because they do not involve overt responses until the end of the trial block, the stimulus-locked ERPs in these tasks are less likely to be contaminated by differential response-related activity. This experiment thus provides a further means of determining whether the anterior portion of the N1 discrimination effect is the result of response-related processes. In addition, it allows us to determine whether the posterior N1 discrimination effect can be obtained even in the absence of an overt response.

In this experiment, we shortened the SOA considerably to discourage subjects from engaging in the discrimination unnecessarily during the simple counting task. This shortened SOA may also reduce anticipatory activity before the stimuli, which may have been present in the previous experiment, because the subject has less time to prepare for each upcoming stimulus array.

Methods

Subjects

Twelve college student volunteers between 18 and 30 years of age (7 men; 3 left-handed) were either paid or received course credit for their participation in this experiment. All subjects had normal or corrected-to-normal acuity, reported normal color vision, and had no history of neurological disorders.

Stimuli and Procedure

The stimuli and procedure were identical to those used in Experiment 1 with the following exceptions. The SOA was shortened to a range of 700–1,100 ms. Four conditions were used: choice-RT, simple-RT, choice-counting, and simple-counting. The two RT tasks were identical to the sRT-normal and cRT-color conditions used in Experiment 1. In the color-counting condition, subjects were required to silently count the number of target-present trials presented during each block of trials. In the simple-counting condition, subjects counted the total number of stimuli presented within each block (disregarding color). In each counting condition, subjects reported the current count during a short break that was interposed after every 55–70 trials. Both the total number of trials and the number of target-present trials presented within each block varied randomly from block to block. Subjects were not permitted to count aloud. Subjects performed two blocks in each condition, yielding the same total number of trials per condition as in Experiment 1. The order of blocks was counterbalanced across subjects.

Recording and Analysis

The same EEG and EOG procedures were used as in the previous experiment. EOG artifacts led to the rejection of 12% of trials (maximum of 18%) in this experiment. Accuracy for the counting tasks was quantified in terms of the percentage of errors in the subject's count, calculated as the absolute value of: (number of targets $-$ number of targets reported) $\div$ number of targets.

Results

Behavior

Accuracy and mean RT for this experiment are summarized in Table 2. Accuracy for all tasks was high and did not differ significantly across conditions, $F < 1$. As in the previous experiment, subjects had faster RTs during the simple-RT condition than during the choice-RT condition, $F(1,11) = 53.69$, $p < .01$.

Electrophysiology

The grand-average ERP waveforms for target-absent trials are shown in Figure 6. As in the previous experiment, a considerably larger inferoposterior N1 peak was elicited in the choice-RT condition than in the simple-RT condition, $F(1,11) = 22.41$, $p < .001$. In addition, a larger posterior N1 was elicited in the choice-counting condition than in the simple-counting condition, $F(1,11) = 9.45$, $p < .05$.

At anterosuperior electrode sites, the N1 was slightly larger in the choice-RT condition than in the simple-RT condition, but this effect was not significant, $F(1,11) = 1.15$, $p = .31$. There was also no significant difference in anterior N1 amplitude between the choice-counting and simple-counting conditions, $F < 1$.

At inferoposterior sites, a larger N2 wave was elicited in the choice-RT condition than in the simple-RT condition, $F(1,11) = 22.77$, $p < .001$, and a larger N2 was also elicited in the choice-counting condition than in the simple-counting condition, $F(1,11) = 16.64$, $p < .01$.

To compare the N1 effect for the counting and RT tasks, the right column of Figure 6 shows difference waves that were constructed by subtracting simple-task activity from choice-task activity for the RT and counting tasks. Although the difference waves tended to be somewhat more negative for the RT tasks than for the counting tasks, there were no significant differences in the posterior N1 wave, $F(1,11) = 1.85$, $p = .20$, or the posterior N2 wave, $F < 1$.

Discussion

The posterior N1 discrimination effect was observed in this experiment for both RT and counting tasks, but the anterior N1 discrim-

Table 2. *Mean Errors and RT for Each Condition in Experiment 2*

Condition	% Errors	Target RT	Nontarget or simple RT
Choice-RT	3	470 (17)	381 (14)
Choice-Count	2	*na*	*na*
Simple-RT	1	*na*	299 (7)
Simple-Count	3	*na*	*na*

RT = reaction time.
SEM in parentheses.

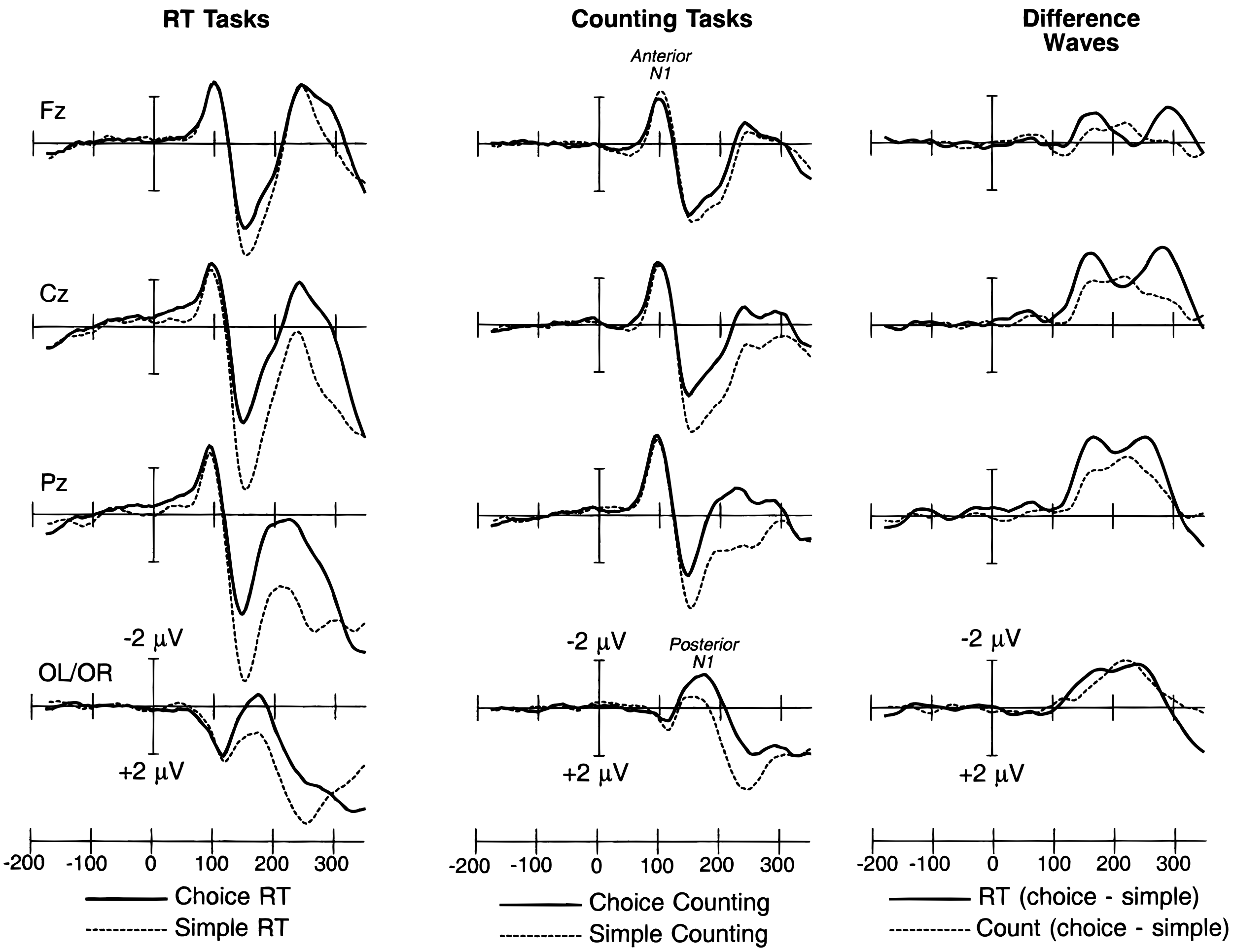

Figure 6. Grand-average event-related potential (ERP) waveforms for target-absent trials in Experiment 2. The first column displays the Color-reaction time (Color-RT) and simple-RT conditions. The middle column displays activity during the choice-count and simple-count conditions. The right column displays difference waveforms computed by subtracting activity during the simple condition from the choice condition for both the counting and RT tasks.

ination effect was absent from both tasks. The elimination of the anterior N1 effect may be a result of the decreased SOA, which may have disrupted preparatory activity. These findings further support the hypothesis that the anterior N1 effect found in the first experiment was due to response-related or preparatory processes that overlapped in time with the stimulus-elicited response. The finding of a posterior N1 discrimination effect in the counting task, however, provides further evidence that this effect is unrelated to motor processing and very likely reflects some aspect of the visual discrimination process.

EXPERIMENT 3

The results of the two previous experiments are consistent with the proposal that the N1 difference between simple- and choice-RT tasks reflects a general-purpose discrimination mechanism, rather than nonspecific factors such as arousal or motor-related overlap. However, it is possible that this difference does not reflect a discrimination process per se, but is instead the result of a greater perceptual load during the choice task relative to the simple task. The concept of perceptual load has gained popularity recently as a determining factor for the locus of attentional selection, with tasks that provide high perceptual loads necessitating perceptual level selective attention (e.g., Lavie, 1995; Lavie & Tsal, 1994). This perceptual resource interpretation of the N1 discrimination effect is consistent with a recent study by Handy and Mangun (in press), who examined the effects of perceptual load on the early visual-evoked components during a spatial attention task. In particular, they found that the posterior P1 and N1 components exhibited larger *spatial* attention effects for difficult letter discrimination tasks than for easy letter discrimination tasks, indicating that perceptual load appears to be an important factor in mediating spatial attention. It is therefore possible that the N1 discrimination effect described in the previous experiments is at least partially the result of a higher level of concentrated resources for the choice-RT condition than for the simple-RT condition.

Experiment 3 addressed the question directly of whether the N1 effect observed in Experiments 1 and 2 reflects a discrimination process or a more general concentration of visual resources by comparing the N1 discrimination effect obtained during an easy discrimination task with that obtained during a difficult discrimination task. If the amplitude of activity during the N1 latency is influenced directly by the amount of concentrated perceptual resources, then a difficult discrimination—presumably requiring greater perceptual resources—should engender a larger N1 effect than an easier discrimination that requires fewer focused resources. In this experiment, we compared two separate color-choice tasks in which we manipulated discrimination difficulty. The easy discrimination task was identical to the cRT-color task of Experiment 1, in which subjects searched for a red target among blue, gray, green, brown, or violet distractors. Conversely, in the difficult discrimination task subjects searched for the same red target among varying shades of purple and pink distractors, thus making the target much more difficult to detect because of the physically similar distractors.

Methods

Subjects

Ten college student volunteers between 18 and 30 years of age (4 men; 1 left-handed) were either paid or received course credit for their participation in this experiment. All subjects had normal or corrected-to-normal acuity, reported normal color vision, and had no history of neurological disorders.

Stimuli and Procedure

Four conditions were used: cRT-Easy, sRT-Easy, cRT-Hard, and sRT-Hard. The stimuli and procedure for the cRT-easy and sRT-easy conditions were identical to those used in the cRT-color and sRT-normal conditions in Experiment 1, respectively. The cRT-hard and sRT-hard conditions differed from the cRT-easy and sRT-easy conditions only in terms of the colors of the distractor stimuli. Five shades of purple and pink distractor colors were used in these hard conditions, the CIE-UCS color coordinates of which were: $u' = .400$, $v' = .426$; $u' = .323$, $v' = .452$; $u' = .445$, $v' = .382$; $u' = .301$, $v' = .475$; $u' = .359$, $v' = .374$.

Recording and Analysis

The same EEG and EOG procedures were used as in the previous experiment. EOG artifacts led to the average rejection of 17% of trials (maximum of 24%) in this experiment. The use of different distractor colors for the easy and hard cRT conditions prohibits direct comparisons of the stimulus-evoked activity because of physical stimulus differences. However, it is permissible to compare the discrimination effects for the easy and hard conditions by using choice-minus-simple difference waves because the stimulus-evoked activity should be subtracted from the waveforms. Therefore, we created difference waves by subtracting the activity recorded during each sRT condition from the activity of its respective cRT condition (i.e., cRT-easy minus sRT-easy vs. cRT-hard minus sRT-hard).

Results

Behavior

Accuracy and mean RT for this experiment are summarized in Table 3. Accuracy was high and did not significantly differ across conditions ($F < 1$). As in the previous experiments, RTs for the simple tasks were faster than those for the choice tasks, resulting in a significant main effect of condition, $F(3,9) = 76.7$, $p < .001$, $\epsilon = 0.53$. Moreover, the mean RTs for the difficult discrimination task were significantly slower than those for the easy discrimination task, $F(1,9) = 64.24$, $p < .001$.

Table 3. *Mean Accuracy and RT for Each Condition in Experiment 3*

Condition	% Correct	Target RT	Nontarget or Simple RT
Easy-cRT	97	474 (21)	352 (32)
Hard-cRT	95	543 (34)	478 (31)
Easy-sRT	98	*na*	301 (8)
Hard-sRT	97	*na*	296 (10)

RT = reaction time; cRT = choice-RT; sRT = simple RT.
SEM in parentheses.

Electrophysiology

The grand-average ERP waveforms for target-absent trials and difference waves are shown in Figure 7. Consistent with the results of the previous experiments, there was a significant N1 discrimination effect at inferoposterior sites for both the easy and hard tasks (both ps $< .01$). However, there was no significant difference between the easy-cRT and hard-cRT conditions in this latency range, $F(1,9) = 1.11$, $p = .32$. There was, however, a significant difference between these two conditions in the latency range of the posterior N2 wave, with the hard-cRT condition eliciting a larger negative wave, $F(1,9) = 5.36$, $p < .05$.

Discussion

As in Experiments 1 and 2, a substantial posterior N1 discrimination effect was observed for both the easy-cRT and hard-cRT conditions. However, the size of this effect was equal for the easy and hard conditions. In contrast, the hard-cRT condition elicited a larger posterior N2 and much slower RTs than the easy-cRT condition. This pattern of results suggests that the hard-cRT condition was indeed more difficult and presumably required more perceptual resources than the easy-cRT condition. Therefore, the results of this experiment do not support the hypothesis that N1 amplitude is simply proportional to the degree of perceptual load and that the N1 discrimination effect is a consequence of differences in perceptual load rather than differences in discrimination requirements per se.

It could be argued that the easy and hard conditions of the present experiment did not differ in perceptual load sufficiently to observe an effect on N1 amplitude. Two factors argue against this possibility, however. First, the difference in RT between the easy- and hard-cRT conditions was more than twice the size of the difference in RT between the sRT conditions and the easy-cRT conditions. Second, the N2 wave did show a substantial and highly significant effect of difficulty. Thus, it is not tenable to argue that the manipulation of task difficulty was too weak to yield a significant increase in N1 amplitude.

It could also be argued that the lack of a difference between the easy-cRT and hard-cRT conditions reflects a ceiling effect, in which the maximal perceptual resource allocation is already reached during the easy-cRT condition, resulting in no increase in resource allocation for the hard-cRT condition. However, previous studies have shown that perceptual load manipulations are effective for tasks that are much more difficult than the easy color discrimination task used in the present experiment (e.g., Lavie, 1995; Handy & Mangun, in press). A ceiling effect is therefore an unlikely possibility.

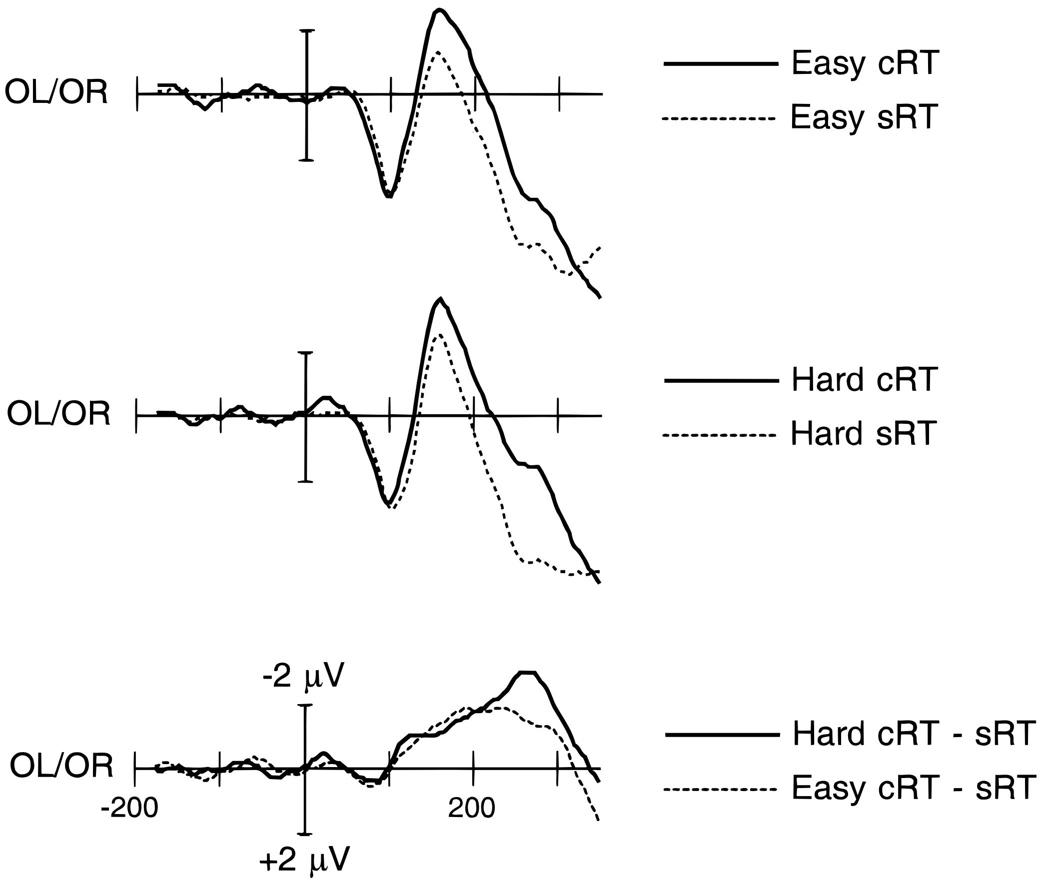

Figure 7. Grand-average event-related potential (ERP) waveforms for target-absent trials for the easy and hard conditions in Experiment 3 are displayed in the top two rows. The difference waves displayed in the bottom row were constructed by subtracting the activity elicited during the easy-simple reaction time (easy-sRT) condition from the easy-choice-RT (easy-cRT) condition, and by subtracting the activity elicited during the hard-sRT condition from the hard-cRT condition.

GENERAL DISCUSSION

The N1 Discrimination Effect

The present study found a larger N1 wave for choice-RT tasks, in which the subjects were required to differentiate between two classes of stimuli, than for simple-RT tasks, in which no discrimination was required. This finding replicates the primary effect described by Ritter and colleagues (1982, 1983, 1988) and is also consistent with previous studies of spatial attention (e.g., Mangun & Hillyard, 1991). In addition, we found that this effect is equivalent for form and color discriminations, indicating that the process reflected by the N1 discrimination effect is more general than the pattern recognition process proposed by Ritter et al. (1983).

As in the study of Ritter et al. (1983), the N1 discrimination effect in Experiment 1 was distributed broadly across the scalp. However, this effect can be subdivided into two distinct N1 effects with different time courses and scalp distributions. The first effect peaked around 100 ms and was present at anterosuperior electrode sites; the second peaked around 160 ms and was present at inferoposterior sites (see Figure 3). However, the anterior N1 discrimination effect was eliminated by a manipulation that was designed to minimize contributions from response-related processes, and we therefore conclude that this effect does not directly reflect the discrimination process. In contrast, the posterior N1 effect was not influenced greatly by these manipulations, and this effect thus appears to reflect discriminative processing.

Alternative Explanations

Arousal

Although the comparison of simple- and choice-RT conditions would seem to isolate discriminative processes, there are several alternative explanations for the N1 discrimination effect that must be considered. The first potential confound is a difference in arousal across the two conditions, with the choice-RT condition possibly engendering a higher state of arousal than the simple-RT condition. We addressed this issue in Experiment 1 by comparing a speed-stressed simple-RT task with a normal simple-RT task, which allowed us to determine whether an increase in the arousal level during the speed-stressed task would produce an enlarged N1 wave. Such an effect was not observed, and the N1 was actually slightly smaller in the speed-stressed simple-RT condition than in the normal simple-RT condition. Thus, it is very unlikely that the N1 discrimination effect reflects increased arousal in the choice-RT task.

Motor-Related Activity

Differences in the timing of response-related potentials provide an additional alternative explanation for the N1 discrimination effect found in Experiment 1. We accounted for this difference in motor-related activity in several ways.[6] In Experiment 1, we attempted to estimate and remove motor-related activity by means of filtering techniques. Although these procedures appeared to eliminate most of the overlap, they are relatively unselective procedures that can cause significant distortions of the waveforms. Therefore, Experiment 2 was conducted to provide an alternative means of attenuating motor potentials, namely the complete elimination of motor responses, which eliminated the anterior N1 discrimination effect but not the posterior N1 effect. In the counting tasks, it is possible that the process of covertly tallying the count from trial to trial contributed to the ERPs. However, it seems unlikely that this activity would manifest itself in the precisely same way as a motor response. These results provide converging evidence that the anterior N1 discrimination effect is due largely to nonspecific ERP activity and that the posterior N1 discrimination effect most likely reflects some sort of visual discrimination process.

Processes Other Than Discrimination

The most obvious difference between simple- and choice-RT tasks is the need for some additional discrimination process during choice-RT tasks. However, it is possible that the N1 discrimination effect actually reflects some choice-RT-related process other than discrimination. Experiment 3 addressed one possible alternative, namely differences in perceptual resource allocation. However, this hypothesis cannot explain the N1 discrimination effect sufficiently because this effect was insensitive to a direct and large manipulation of perceptual load.

An additional possibility is that the N1 discrimination effect reflects a difference in the visual processing streams used for performing the simple and choice tasks. Specifically, the color and form discrimination tasks likely require ventral stream processing, whereas the simple-RT conditions may rely exclusively on dorsal stream processing for rapidly detecting a luminance onset. However, we tested this hypothesis recently in a separate study that compared the N1 discrimination effect observed for color-based discriminations with direction-of-motion-based discriminations and found no difference between discriminations of the "ventral" feature of color and the "dorsal" feature of motion (Vogel & Luck, 1997). Thus, it seems unlikely that the N1 discrimination effect reflects a dorsal-ventral difference between the simple and choice tasks, although it is still possible that this effect is due to some other subtle anatomical difference in processing.

The N1 Discrimination Process

Because we have ruled out the most likely alternative explanations, it appears likely that the posterior N1 discrimination effect reflects the operation of a visual discrimination mechanism. The present study has provided an initial step toward elaborating the nature of this mechanism. In particular, we have demonstrated that this effect is present for both color- and form-based discriminations and does not require a motor response. However, there are a number of characteristics of this mechanism that presently remain unspecified. One significant issue is the precise relationship between this discrimination effect and the N1 spatial attention effect (e.g., Luck, 1995; Mangun, 1995). These two effects are similar in time course, scalp distribution, and the task conditions under which they are observed. Previous studies of spatial attention have indicated that the N1 attention effect reflects some form of purely facilitative mechanism of attention that is applied to a location in space, and if the N1 discrimination effect reflects the same cognitive operation, it follows that the N1 attention effect reflects the operation of a discriminative mechanism at the attended location. However, it is difficult to compare these different effects directly. In particular, spatial attention experiments rely on a comparison of stimuli at attended versus unattended locations, whereas the N1 discrimination effect is based on a comparison between conditions in which all stimuli are presented at attended locations. Thus, it is not clear what the relationship is between these two N1 effects, and future research will be necessary to address this issue. However, the present study represents the necessary first step towards that end.

The timing of the N1 discrimination effect can also be used as a measure of the onset of discriminative processing. In the present experiments, the posterior N1 discrimination effect began consistently between 100 and 125 ms poststimulus, and thus provided an estimate of the onset of controlled discriminative processing. Because it is possible that there is an even earlier discrimination process that is not reflected in the ERP waveforms, this estimate of 100–125 ms should be considered an upper bound on the onset of discriminative processing. Thorpe, Fize, and Marlot (1996) used similar reasoning to demonstrate that the brain can begin to differentiate between pictures of real-world scenes that did or did not contain an animal within 150 ms after stimulus onset. Specifically, beginning at approximately 150 ms poststimulus, a larger negativity was present for animal pictures versus nonanimal pictures at frontal sites, thereby indicating that the visual system had differentiated between the two abstract classes of pictures by this time point. When this finding is combined with the results of the present study, it appears that the brain begins to perform controlled, discriminative processing within 100–125 ms of stimulus onset and begins to have some information about abstract stimulus identity within an additional 50 ms.

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[6] In addition to the methods described in this article, we have completed two additional experiments that control for motor-related overlap. In the first experiment we instructed subjects to respond with the same latency for both the cRT and sRT conditions. When response latencies were equated, the anterior N1 discrimination effect was eliminated but the posterior effect remained intact. In the second experiment, we used a highly variable SOA to reduce anticipatory motor-related activity and again found that the anterior N1 effect was eliminated but the posterior N1 effect remained intact.

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