Context Modulates Early Stimulus Processing when Resolving Stimulus-response Conflict

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Abstract

When responding to stimuli in our environment, the presence of multiple items associated with task-relevant responses affects both ongoing response selection and subsequent behavior. Computational modeling of conflict monitoring and neuroimaging data predict that the recent context of response competition will bias the selection of certain stimuli over others very early in the processing stream through increased focal spatial attention. We used high-density EEG to test this hypothesis and to investigate the contextual effects on nonspatial, early stimulus processing in a modified flanker task. Subjects were required to respond to a central arrow and to ignore potentially conflicting information from flanking arrows in trials preceded by a series of either compatible or incompatible trials. On some trials, we presented the flanking arrows in the absence of the central target. The visual P1 component was selectively enhanced only for incompatible trials when preceded by incompatible ones, suggesting that contextual effects depend on feature-based processing, and not only simple enhancement of the target location. Context effects also occurred on no-target trials as evidenced by an enhanced early-evoked response when they followed compatible compared to incompatible trials, suggesting that spatial attention was also modulated by recent context. These results support a multi-componential account of spatial and nonspatial attention and they suggest that contextually driven cognitive control mechanisms can operate on specific stimulus features at extremely early stages of processing within stimulus-response conflict tasks.

INTRODUCTION

At any point in time, multiple stimuli in the environment compete for attention and action. The control of such conflict has been investigated by manipulating the interference of irrelevant stimulus dimensions with task-relevant responses. In the flanker task (Eriksen & Eriksen, 1974), processing of a target stimulus and the production of its associated response are influenced by irrelevant flanking stimuli that are associated with either an identical response or a different one. When the flanking stimuli are identical to the target (compatible trials), responses are faster and more accurate than when the identity of the flankers conflicts with that of the target (incompatible trials). A number of models have been proposed to account for the cognitive factors underlying stimulus-response conflict (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Eimer, Hommel, & Prinz, 1995; Zorzi & Umilta, 1995; Kornblum, 1994; Cohen, Servan-Schreiber, & McClelland, 1992). Many of these theories suggest the activation of two routes: a fast, direct route that is preferentially dedicated to well-learned or habitual stimulus-response associations, and an indirect route that influences behavior through controlled stimulus-response translation rules.

Although the existence of stimulus-response compatibility effects and the validity of dual-process models are undisputed, recently the notion that these can be accounted for by processes that operate on response selection on a trial-by-trial basis has been seriously challenged. In particular, the recent behavioral context (i.e., which stimuli have been recently seen and responded to) seems to be an important factor modulating the size of these effects. For example, in the spatial domain, the effects of stimulus-response incompatibility (e.g., the Simon effect) can be eliminated and even reversed on the bases of previous responses (Lu & Proctor, 1995). Similarly, if incompatible trials are very frequent, the compatibility effect decreases, whereas it increases for infrequent incompatible trials (Riddervold, 2002). This strongly suggests that, at the behavioral level, the overall context within which subjects exert their cognitive control modulates stimulus-response conflict.

In the flanker task, incompatible trials result in faster responses if they are preceded by an incompatible...
trial than if they are preceded by a compatible one, suggesting improving inhibitory control whenever a previous trial requires inhibiting an incompatible response (Gratton, Coles, & Donchin, 1992), a phenomenon labeled the “Gratton” or “conflict adaptation” effect. The processes underlying it have been highly debated (cf. Botvinick, Cohen, & Carter, 2004; Mayr, Awh, & Laurey, 2003). For example, Mayr et al. (2003) suggested that the advantage provided by preceding incompatible trials depends on the fact that, on a proportion of trials, incompatible trials of interest represent identical repetition of previous incompatible trials. These contingencies would account for the effects first reported by Gratton et al. (1992). However, Kerns et al. (2004) recently replicated contextual effects even when repetitions were excluded from analysis, arguing that sequential effects could not be fully accounted for by repetition priming.

Together with the controversy on the behavioral findings and their interpretation, the neural bases of contextual effects have attracted much interest from cognitive neuroscientists. Indeed, they afford an opportunity for investigating the neural mechanisms underlying how control of stimulus-response mappings can be flexibly modulated on the basis of previous events. Neuroimaging studies have shown increased activity in the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) regions, as well as in the superior parietal cortex (e.g., van Veen, Cohen, Botvinick, Stenger, & Carter, 2001; Carter et al., 1998; Carter, Mintun, & Cohen, 1995) in tasks that require the flexible control of conflict. These regions appear to serve distinct but complementary roles. An influential theory posits the ACC to be involved in the monitoring of conflict when there are competing responses (Botvinick et al., 2004; Kerns et al., 2004; Botvinick et al., 2001; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; van Veen et al., 2001; but see Mayr et al., 2003, for an alternative account of ACC function), or whenever very infrequent responses are required, even during performance of otherwise simple discrimination tasks (Braver, Barch, Gray, Molfese, & Snyder, 2001). Furthermore, a distributed network of regions including the parietal cortex and DLPFC has been proposed to allow attending to relevant information by biasing the processing of relevant over irrelevant dimensions, resulting in the reduction of conflict (e.g., Durston et al., 2003; Bunge, Hazeltine, Scanlon, Rosen, & Gabrieli, 2002; Casey et al., 2000). Activation of a similar network has been shown with a modified version of the flanker task that incorporates alerting and spatial cueing (Fan, McCandliss, Sommer, Raz, & Posner, 2002) and in selective attention tasks such as cued global/local feature processing of hierarchical stimuli (Weissman, Mangun, & Woldorff, 2002) or those involving interference from task-relevant distractor stimuli across modalities (e.g., Weissman, Warner, & Woldorff, 2004). Although much of the literature has focused on response selection processes, other attentional mechanisms may also play a role in the effects of preceding events on trials of interest. Conflict might be controlled early in the processing pathway through sensory gating of task-relevant and irrelevant stimuli. In the case of the flanker task, Casey et al. (2000) hypothesized that, with consecutive incompatible trials, spatial attention may be increasingly directed to the target, rather than to the flanking stimuli, resulting in increased target selection. In contrast, if preceding trials do not require increased target selection (as in the case of compatible flankers), a suddenly appearing incompatible trial should be characterized by an initial lower focus on the target and greater difficulties in suppressing conflicting information from the flankers. Consistent with these predictions, Casey et al. found increased activity in superior parietal and superior frontal cortices—areas that have been implicated in directing of attention—when subjects were presented with successive incompatible trials. These interactions between conflict monitoring and the control spatial attention in the flanker task have been modeled computationally by Botvinick et al. (2001). Closely reproducing previous behavioral data, their model posits that information from a conflict monitoring node outputs to a spatial attention layer from trial to trial. High levels of previous conflict lead to increased attentional focus onto the center of a flanker stimulus, whereas lower earlier levels of conflict lead to a more even distribution of input to the spatial attention layer.

In addition to spatial orienting, attention has been shown to operate in the domain of specific stimulus features such as color, motion, and spatial frequency (e.g., Van Rullen, Reddy, & Koch, 2005; Allen & Ledgeway, 2003; Sowden, Ozgen, Schyns, & Daoutis, 2003). To the extent that target and distractor items differ along such specific featural dimensions, these nonspatial attention processes may also be a mechanism by which early sensory gating is achieved in response to the detection of response conflict. Such spatial and feature-based mechanisms may act in a complementary, rather than mutually exclusive, fashion and be distinguished by examining their temporal dynamics in relation to stimulus and task context.

Event-related potentials (ERPs) offer the high temporal resolution necessary to test predictions that the context set by previous response conflict will modulate early sensory processing. A number of ERP studies have addressed the temporal dynamics underlying the control of stimulus-response conflict. These studies have found reliable differences in ERP waveforms between high- and low-conflict conditions across a number of stimulus-response conflict tasks in components associated with motor preparation (lateralized readiness potential [LRP], e.g., Mattler, 2003) or late response-related components (P300 and N200/N2c or ERN, van Veen & Carter, 2002; Kopp, Mattler, Goertz, & Rist, 1996; Kopp, Rist, &
Mattler, 1996). For example, 50 to 150 msec following the commission of an error, a large negative deflection named the error-related negativity (ERN) is observed in the ERP, with a maximum over frontal or central sites (Pailing, Segalowitz, Dywan, & Davies, 2002; Gehring, Goss, Coles, Meyer, & Donchin, 1993; Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991). These studies have tended to focus on the modulation of ERP components by stimulus-response conflict on a trial-by-trial basis rather than on the contextual effects of previous conflict as has been the case more recently in fMRI studies discussed above. In addition, the majority of these studies target mechanisms of cognitive control associated with anterior networks including ACC, DLPFC, but not their modulation of visual attentional selection.

However, if sensory gating is an important means by which context-related control over conflict is engaged, then we might expect to see a modulation of early sensory electrophysiological components similar to those seen for other visual attentional manipulations. Early stimulus-related components of the ERP are known to be modulated by spatial and feature-based attentional mechanisms. Studies investigating these mechanisms primarily rely on the contextual effects of various types of attention directing cues on selection. For spatial attention, the amplitude of early posterior components such as the P1 and N1 is enhanced for stimuli presented at attended locations compared to unattended locations (e.g., Luck et al., 1994; Eimer, 1993, 2000; Mangun & Hillyard, 1991). Attention directed to visual stimulus features typically results in a somewhat later modulation, referred to as a selection negativity (Harter & Aine, 1984). Interestingly, modulation of these early components has not been used to test contextual effects on the control of stimulus-response conflict. The question remains as to whether contextually driven changes related to the processing of stimuli in the flanker task would be akin to the effects of attentional cueing.

In the current study, we focused on the modulation of the early visual evoked potential by the preceding response context in the flanker task. Trials of interest were preceded by a series of compatible or incompatible trials, therefore manipulating both the configuration of stimuli in each of these trials and the context preceding them (as illustrated in Figure 1). In addition, some trials presented only the flanker stimuli and no central arrow. We examined several ways in which context might affect early stimulus processing as indexed by modulation of the first deflection in the evoked potential. The visual ERP consists of a series of positive and negative deflections starting at approximately 80–100 msec and continuing for several hundred milliseconds depending on the nature of the stimuli and task. We focused our analysis on the P1 component, which is the first prominent positive deflection, as it is well established that this is the first component that is robustly modulated by visual spatial attention. Although attention to nonspatial features is often reflected as a slightly later modulation, we restricted our analysis of nonspatial features to this window as well because we expected spatial and featural attention to be engaged together to resolve conflict. Modulations of ERPs at these early latencies have been previously reported in response to attention to conjunctions of features and location (Zani & Proverbio, 1997).

First, we hypothesized that if contextual effects were mediated by simple spatial attention, then markers of early stimulus processing, in particular the amplitude of visual P1, should be reduced in the incompatible context because a more restricted focus of attention leads to less...
effective stimulation and suppression of distracter (flanker) locations is associated with P1 reduction (Luck et al., 1994).

Second, we asked whether effects on the early evoked potential would also be dependent on the characteristics of the flanker stimuli in each trial of interest. Feature-based modulation of stimulus processing by previous context would be indexed by an interaction between context and array characteristics on the visual P1. In the context of previous conflict, we expected incompatible trials of interest to show an enhanced early response relative to compatible trials. However, we did not make a specific prediction regarding the relative size of each of the responses compared to trials in which there was a context of previous compatibility. For example, feature-based attention might result in either amplification of a matching stimulus or suppression of a nonmatching stimulus. Indeed, as these early effects may be modulated by priming of stimulus features by trials preceding the trials of interest, we counterbalanced for each trial type whether the trial of interest represented a repetition or a change compared to the previous one.

Third, in order to investigate the nature of the effects of context on early stimulus processing, we directly compared two conditions in flanker stimuli that were missing the central target arrow (no-target trials). During these trials, identical flanker arrays in which the central target was missing were preceded by a series of either compatible trials or incompatible trials. If preceding context affects the nature of the attentional focus on the flanker array, causing it to be more distributed in a compatible context and more focused in an incompatible context, then identical no-target flanker stimuli should produce a relatively smaller stimulus-evoked potential when preceded by an incompatible context because of the lack of stimulation at the focus of attention and/or relative greater flanker suppression.

METHODS

Participants

Eleven participants (19 to 33 years old, mean age, 24.4 years) were recruited from the subject pool of the Sackler Institute of Developmental Psychobiology and paid for their participation. Informed consent was obtained according to the regulations set by the Institutional Review Board of the Weill Medical College of Cornell University.

Procedure

Behavioral Task

Subjects viewed horizontal arrays of arrowheads and pressed one of two buttons for each trial to indicate whether the central arrowhead pointed right or left. Button presses were with the left or right hand for left- and right-pointing arrows, respectively. They were required to ignore potentially conflicting information from flanking arrows. Stimuli were composed of arrays of either seven arrowheads (target trials) or six arrowheads (no-target trials). The central target arrow pointed to the left or the right. The remaining six flanking arrows pointed either in the same direction as the target (compatible stimuli) or in the opposite direction (incompatible stimuli). Viewed from a distance of 75 cm, the overall flanker array subtended a 10.7° × 0.9° angle.

Stimuli were presented for 1000 msec and were presented at a fixed intertrial interval of 2500 msec. Participants completed 16 blocks of 120 trials each (with two brief rest intervals per block to allow for fatigue). Stimulus conditions were presented in a pseudorandom trial sequence within which trials of interest were embedded. We manipulated both the context preceding the trials of interest and the configuration of the stimuli in the trials of interest. All trials of interest were preceded either by three compatible trials in a row or three incompatible trials in a row. This number of trials of a given compatibility preceding the trial of interest depended on the concurrent use of this trial sequence for a parallel functional imaging experiment, and was aimed at deconvolving from noise the hemodynamic response for the trials of interest.

For any given trial of interest, the stimuli themselves could comprise a compatible array, an incompatible array, or a no-target array in which only the flankers were present and there was no central arrow. Subjects were instructed to withhold a response for no-target trials. Thus, there were a total of six conditions of interest (illustrated in Figure 1): (1) compatible trials preceded by three consecutive compatible (labeled cC hereafter) or (2) three incompatible (labeled iC hereafter) trials; (3) incompatible trials were preceded by three consecutive compatible (labeled cI hereafter) or (4) three incompatible (labeled iI hereafter) trials; (5) flanker arrays that did not contain target arrows and were preceded by three compatible (labeled cNoT hereafter) trials and (6) no-target flanker arrays that were preceded by three incompatible trials (labeled iNoT hereafter).

The trial sequence contained equal numbers of cC, cI, iC, iI, cNoT, and iNoT trials (80 per trial type). Blocks were fully counterbalanced for the number of trials in the various conflict conditions, response side, and their combination. Furthermore, to control for the potential effects of stimulus-repetition priming on early stimulus processing as well as later response-related components (Mayr et al., 2003), trials of interest were counterbalanced for whether they involved a repetition or a change compared to the preceding trial. Trials of interest were distributed in the following pseudorandomized fashion: There were 5 trials of interest for each of the 6 conditions in each of the 16 runs (120 trials each). Given this
careful counterbalancing procedure, we doubted that changes in compatibility could be predicted by participants. However, at debriefing we asked them whether they had detected particular trends in the trial sequence. They either responded that they had not or responded that they had focused on changes in right–left responses, rather than compatibility.

**EEG Recording and Data Processing**

Data were collected by using Net Station hardware and software and 128-channel geodesic sensor arrays (Electrical Geodesics Inc., Eugene, OR) referenced to the vertex, recording at 0.01–100 Hz. Analyses were conducted by using Net Station 4.0 software. Epochs spanned 1000 msec prestimulus to 1200 msec poststimulus. Segments were corrected for overall drift to the whole segment prior to artifact rejection. Off-line artifact rejection was conducted with an automated search algorithm (Electrical Geodesics Inc.), whose accuracy was also evaluated by visual inspection. Bad channels were replaced through spherical spline interpolation algorithm (Electrical Geodesics Inc.), whose accuracy was also evaluated by visual inspection. Segments were baseline corrected to 200 msec preceding stimulus onset. A band-pass filter (0.1–30 Hz) was applied to the data that were subsequently average referenced.

For target trials, visual inspection of the topography of grand-averaged difference waveforms was used to determine the peak latency for the first positive deflection. All contiguous channels whose amplitude was >50% of the peak amplitude were selected as the channels from which to extract the amplitude of the component. In individual subjects, the precise timing of the maximum first positive deflection might vary within the time window between 70 and 130 msec poststimulus onset. Adaptive means allow for this variability by calculating for each subject the mean amplitude for the ERP of an amplitude of 50% or more from the maximum peak, whether this falls entirely within the set time window or not.

For no-target trials, visual inspection of the topography of the difference waveforms highlighted a peak at approximately 84 msec poststimulus onset. The amplitude of medial to right-lateralized electrodes exceeded 50% of the peak amplitude. The mean amplitude across no-target trials was calculated for those channels within the time window between 70 and 90 msec poststimulus onset.

**RESULTS**

**Behavioral Findings**

Mean reaction times for accurate responses to the central target were calculated for each subject in compatible and incompatible trials preceded by a compatible or incompatible context, separately. Reaction times above 1000 msec or below 200 msec were discarded to avoid the undue influence of outliers on mean response times, but the final analyses were run both with the original data set and with the cropped data set. As the two analyses yielded converging results, analyses on the cropped means are reported, as these meet the assumptions of parametric statistics.

A 2 × 2 analysis of variance (ANOVA) with conflict (compatible, incompatible) and context (compatible, incompatible) as the within-subject factors was conducted on mean correct response times during the EEG session. Conflict had a statistically significant effect on reaction times, \( F(1,10) = 63.094, p < .001 \), partial eta squared = .944. Consistent with the predicted combined effect of conflict and previous response context (Gratton et al., 1992), the interaction between conflict and context also reached significance, \( F(1,10) = 7.562, p = .02 \), partial eta squared = .431. Reaction time was slowest for incompatible trials preceded by compatible flanker arrays (cI trials, \( M = 518.28 \pm 15.7 \) msec). These responses were slower than those on trials in which an incompatible array was preceded by incompatible trials, iI trials, \( M = 512.18 \pm 16.17 \) msec, \( t(10) = 3.055, p = .013 \). In turn, responses in iI trials were slower than in trials in compatible flanker arrays preceded by incompatible trials, iC trials, \( M = 475.28 \pm 14.21 \) msec, \( t(10) = 5.742, p < .001 \). Response times on iC trials did not significantly differ from those in which compatible trials were preceded by compatible flanker arrays, cC trials, \( M = 465.2 \) msec, \( SEM = \pm 15.69 \) msec, \( t(10) = 1.825, p = .098 \).

To investigate further the potential role of repetition priming in driving the Gratton effect demonstrated behaviorally here, we also conducted a 3 × 2 × 2 repeated measures ANOVA with repetition (repetition, change), conflict (compatible, incompatible), and context (compatible, incompatible) as within-subject variables. Repetition had a statistically significant main effect on reaction time, \( F(1,10) = 21.732, p = .001 \), partial eta squared = .685, due to faster response times for change (on average, 479.6 msec) than for repetition trials (507.1 msec). Conflict continued to have a statistically significant effect on reaction time, \( F(1,10) = 63.991, p < .001 \), partial eta squared = .865. As when all trials were collapsed over repetition and changes, the interaction effect of context and conflict was also statistically significant, \( F(1,10) = 12.645, p = .005 \), partial eta squared = .558. The three-way interaction...
effect of repetition, context, and conflict was not statistically significant, $F(1,10) = 2.159, p = .172$, partial eta squared $= .178$, as is also suggested by overall similar trends in differences across conditions for repetition (cI = 540.5 msec, iI = 523.8 msec, cC = 487.1 msec, cC = 476.9 msec) and change trials (cI = 500.0 msec, iI = 499.5 msec, cC = 464.9 msec, cC = 454.2 msec), respectively.

Similar trends characterized response errors. There was a main effect of context, $F(1,10) = 8.550, p = .015$, partial eta squared $= .461$, but not one of conflict, $F(1,10) = 2.715, p = .130$, partial eta squared $= .214$. The former was due to greater errors in a compatible (6.7 ± .87) versus an incompatible context (4.78 ± .77). The interaction effect of conflict and context was also statistically significant, $F(1,10) = 46.299, p < .001$, partial eta squared $= .822$. This was due to a larger number of errors on cI trials (10.0 ± 1.45) than on iC trials, 6.3 ± .65, $t(10) = 2.947, p = .015$, than on cC trials, 3.4 ± .69, $t(10) = 4.454, p = .001$, and finally on iI trials, 3.3 ± 1.17, $t(10) = 5.167, p < .001$.

Electrophysiological Data

**Target Trials**

P1 amplitude was calculated averaging across channels selected on the basis of the topography of the difference waveform. Figure 2 illustrates channels of interest and the averaged waveform for the four conditions (a), as well as their topography at 112 msec (b). There was a main effect of context, $F(1,10) = 6.955, p = .025$, partial eta squared $= .410$, due to larger amplitude of the channel group for incompatible versus compatible context, but this was also accompanied by a significant interaction between conflict and context, $F(1,10) = 5.597, p = .04$, partial eta squared $= .359$. Analyses of simple comparisons were conducted to evaluate the origin of this interaction. These highlighted that P1 amplitude was higher in iI trials than in any of the other target trials (paired comparisons reported in Table 1). Latency of the P1 was not affected by either context, $F(1,10) = 1.428, p = .260$, conflict, $F(1,10) = .405, p = .539$, or their interaction, $F(1,10) = .001, p = .979$.

To test whether these effects depended on simple stimulus repetition priming, we compared the amplitude of the visual P1 for trials that were an identical repetition of the previous trial, compared to trials that were not. P1 amplitude did not vary depending on repetitions, $F(1,10) = 272, p = .613$. There were also no statistically significant interactions between stimulus repetition and either context, $F(1,10) = .039, p = .847$, or stimulus conflict, $F(1,10) < .001, p = .998$. Finally, there was no statistically significant three-way interac-

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**Figure 2.** Modulation of early processing of target arrays. (A) The averaged waveform over posterior electrodes (indicated on the adjacent channel map) shows greater amplitude of the first positive component in incompatible trials following other incompatible trials (iI trials) than in any of the other conditions. (B) Scalp topography across conditions at 112 msec poststimulus onset illustrating the distribution of components and difference waveforms.
tion effect between repetition, context, and conflict, $F(1,10) = .068$, $p = .799$. Critically, if trials that constituted the identical repetition of the previous incompatible array did not result in lower amplitude of the P1 than those that involved a change, as often occurs with the repetition of identical stimuli.

No-target Trials

Visual inspection of the difference waveform highlighted a medial to right-lateralized difference peaking at 84 msec. We calculated the mean amplitude of the waveforms in the two conditions. Figure 3 illustrates channels of interest and the averaged waveform for the two conditions, as well as their topography at 84 msec. no-target arrays that were preceded by compatible flanker arrays resulted in higher mean amplitude than no-target arrays that were preceded by incompatible trials, $t(10) = 3.514$, $p = .006$ for right posterior electrodes, but not for either medial or left posterior electrodes ($t = 1.1762$ and 1.196, $p = .109$ and .259, respectively).

Table 1. Adaptive Mean Amplitude of the Waveform in cC, iC, ci, and ii Trials for the Visual P1

<table>
<thead>
<tr>
<th></th>
<th>Compatible Context</th>
<th>Incompatible Context</th>
<th>$t(10)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatible trial</td>
<td>$2.39 \pm 0.59 \mu m$</td>
<td>$2.37 \pm 0.46 \mu m$</td>
<td>-0.59</td>
</tr>
<tr>
<td>Incompatible trial</td>
<td>$1.97 \pm 0.60 \mu m$</td>
<td>$3.16 \pm 0.66 \mu m$</td>
<td>-3.272**</td>
</tr>
<tr>
<td>$t(10)$</td>
<td>1.153</td>
<td>2.612*</td>
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*p < .05.

**p < .01.
DISCUSSION

The primary objective of this study was to examine the effects of previous stimulus-response conflict on early stimulus processing as measured by visual evoked potentials. This was motivated by computational models (Botvinick et al., 2001), as well as neuroimaging data (Casey et al., 2000) predicting the interaction between contextually driven cognitive control and visual attention in resolving flanker interference. As predicted, early processing of flanker stimuli was modulated by the context in which they appeared, as well as by the interaction of context with the characteristics of the flanker arrays themselves. First, in target trials the amplitude of the visual P1 component was higher when incompatible stimuli had been preceded by incompatible trials than in any of the other conditions. Second, when no-target flanker trials were presented, the first positive deflection

![Figure 3. Modulation of early processing of no-target arrays in the two different previous contexts (compatible and incompatible). (A) The averaged waveform over posterior electrodes (indicated on the adjacent channel map) shows a greater positivity for no-target trials following a series of compatible, compared to incompatible trials, and (B) its distribution at 84 msec poststimulus onset.](image-url)
in the ERP was higher for those that had been preceded by a context of compatible flanker trials than for those that had been preceded by a context of incompatible flanker trials. Thus, the context set by previous stimulus-response conflict interacted with the stimulus characteristics as early as 100 msec poststimulus presentation.

Unlike other studies on stimulus-response conflict, the current study focused on earlier components thought to originate from posterior cortical areas (Di Russo, Martinez, & Hillyard, 2005) rather than on later ERP components associated with the activity of the ACC and DLPFC (van Veen & Carter, 2002) or on the effects of response conflict on motor preparation (Eimer, 1993, 1999). Our results suggest an earlier interaction of previous stimulus-response conflict and stimulus characteristics in modulating early components such as the visual P1, as has been more traditionally demonstrated by use of attention directing cues (e.g., Luck, Fan, & Hillyard, 1993). We interpret this modulation of the visual P1 as depending on both increased attentional selection on the target and featural characteristics of flanker arrays.

Trials in which flankers were presented but the central target was absent (no-target trials) enhanced our understanding of these early stimulus effects. As we had predicted, in the case of no-target stimuli that were preceded by incompatible flanker arrays, we found a reduced early positive component compared to identical stimuli that were presented in a compatible context. This is consistent with the spatial focus of attention becoming increasingly restricted to the region of the target stimulus when successive incompatible trials require the flanker information to be suppressed, the target to be enhanced (as originally modeled by Botvinick et al., 2001), or both. A plausible suggestion at the physiological level is that this amplitude reduction may result from an increased suppression of processing of the flanking arrows after successive incompatible trials, mediated by the modulation of attentional weights on target–flanker lateral connections (e.g., Freeman, Sagi, & Driver, 2001).

This simple spatial attention mechanism is not sufficient to account for the reversal in polarity of P1 modulation in I I trials. In fact, this reversal supports the additional role of stimulus features in the effect. However, although spatial attention does not seem sufficient to explain the specific interaction between previous context and stimulus type, it is not certain what type of featural attention might have been increased in response to conflict in this specific experiment. One possibility is the spatial frequency domain. The visual system demonstrates selectivity on the basis of spatial frequency (e.g., Sasaki et al., 2001) and attention has been shown to operate in the spatial frequency domain on the basis of both psychophysical (e.g., Ludwig, Gilchrist, & McSorley, 2005; Sowden et al., 2003) and electrophysiological studies (e.g., Baas, Kenemans, & Mangun, 2002; Zani and Proverbio, 1997). Spatial frequency, together with orientation, configuration, and separation, influences systematically lateral interactions across flanking stimuli (e.g., Polat & Sagi, 1994). Indeed, the compatible and incompatible stimuli used in this experiment differed at higher spatial frequencies. In the case of the context set up by a series of previous incompatible trials, attention may have acted to tune to the higher spatial frequency channel corresponding to the incompatible stimuli, resulting in an increased response to this class of stimuli relative to compatible ones. In contrast, just as for spatial attention, a low-conflict context would not require tuning of such feature-specific channels, and therefore no difference would be expected between compatible and incompatible stimuli after a series of compatible trials.

The early timing of these contextually driven modulations in sensory processing is particularly notable. In the case of the no-target trials, in which the effect is consistent with modulation by spatial attention, effects are seen on a component peaking at approximately 84 msec and suggesting differential processing at very low levels of the visual hierarchy. Such an early time course is consistent with reports recording from single cells in monkey primary visual cortex in which attentional modulation of lateral interactions between stimuli arose simultaneously with the responses to the stimuli themselves (Ito & Gilbert, 1999). In comparison, the modulation of the P1 component occurred later, peaking at around 120 msec. However, attention to visual features is usually manifest as a somewhat later selection negativity effect (Harter & Aine, 1984). Taken together, these early latencies may indicate that attentional changes mediated by detection of conflict in the recent context operate somewhat earlier than changes induced by explicit cues. Additional research, perhaps combining EEG with fMRI, is needed to investigate the issue of whether substrates of this modulation are similar to those characteristic of more traditional attentional cueing tasks (e.g., Di Russo et al., 2003).

Our results suggest that at least two mechanisms may be engaged as a result of previous context to help resolve upcoming stimulus conflict. The reduced early response to the no-target trials when preceded by a context of conflict is consistent with the deployment of a spatial attention process. However, the increased response for I I trials relative to all other target trial types indicates that an additional nonspatial process must also be present. Indeed, we thank an anonymous reviewer for pointing out that there is little evidence for a spatial process in the target trials, which seem to be dominated by a feature-based mechanism. For example, the spatial mechanism might be expected to result in reduced P1 amplitude for I C trials relative to C C trials but this was not a statistically significant difference in our data. This invites the question of whether these two mechanisms, which presumably are deployed depending on context
prior to the onset of each trial, are always engaged within this early time frame for any stimulus that might occur, or, conversely, whether they might operate separately and preferentially for some trial types. For example, the more effective process for any given stimulus might be engaged while suppressing the alternate process. Unfortunately, the tight coupling of spatial and featural changes across target conditions in the current experiment does not allow one to separate entirely the relative contribution of spatial and featural modulatory effects. However, their relative involvement in each trial type needs to be investigated further.

Our design manipulation also allowed testing additional influences on early contextual effects, such as repetition priming or preparatory changes prior to stimulus onset. Simple priming could not account for the modulation of P1 in incompatible arrays preceded by incompatible trials (as has been suggested for behavioral effects and ACC activation differences, Mayr et al., 2003). We note here that our primary focus was not on investigating repetition accounts of the Gratton effect at the behavioral level or the involvement of ACC in later response-related processes: As Gratton et al. (1992) first recognized, temporal characteristics of repeated stimulus presentation (intertrial interval, stimulus exposure, etc.) all influence the later behavioral effect, and we did not manipulate these parameters systematically. Instead, we were primarily interested in testing whether our early modulation could be accounted for by priming of previous stimulus configurations. In terms of early stimulus processing, stimuli that represented a change compared to the previous array and those that did not resulted in similar modulation of this early component.

We also believe that these effects are not the result of a simple baseline difference across types of context. Contextual cues such as peripheral flashes and centrally presented arrows affect preparatory components such as the LRP and the contingent negative variation (CNV; Eimer, 1993), as well as early stimulus processing. However, in the current experiment, preliminary analyses indicated that preparatory components such as the CNV (reviewed in Brunia, 1999) and suppression of alpha band activity (as measured by Worden, Foxe, Wang, & Simpson, 2000) were not differentially modulated by the two different types of context. Furthermore, trials that were identical in terms of previous context (II and IC) differed in the degree of P1 modulation, arguing for the role of stimulus characteristics in the effect. This is not to say that either priming or preparatory changes do not play a role in the processing of stimuli when resolving stimulus-response conflict. Additional research in which the task is structured to emphasize the role of these processes will help clarify the relationships between these preparatory processes, early stimulus processing and ongoing control of stimulus-response conflict.

In summary, our findings support the view that attentional selection should be conceptualized as a multi-componential set of processes dynamically recruited by both task demands and the differential perceptual characteristics of visual stimuli in the environment. Similar conclusions have been drawn from a vast literature on the effects of attentional cueing on stimulus processing, but this issue had not previously been considered in relation to how it may relate to stimulus-response conflict.

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