THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY, 2002, *55A* (3), 917–936

Covert orienting to the locations of targets and distractors: Effects on response channel activation in a flanker task

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The role of covert orienting of attention in response channel activation was examined using the flanker interference and precueing paradigms. Four experiments assessed the influence of distractors on the discrimination of a target colour patch under cueing conditions (three with non-informative, exogenous cues and one with informative, endogenous cues) that modulated attention at the flanker or target locations. Across all of the experiments, the amount of interference generated by the distractors was not modulated by the facilitation and inhibition of return induced by spatial attention precues. These results are consistent with previous reports of patients with neglect, which demonstrated that flanker interference proceeds at unattended locations (Audet, Bub, & Lecours, 1991; Cohen, Ivry, Rafal, & Kohn, 1995), and they suggest that response channel activation can occur independently from spatial attention.

Imagine driving down a street that has a continuous sequence of traffic lights. As you approach a green traffic light, the next traffic light ahead is red; and you might begin to respond to the second light by removing your foot from the accelerator. This response often occurs without

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This work was supported by US PHS training fellowship MH19930 to T. Ro and US PHS grant MH41544 to R.D. Rafal. Portions of this work were completed while the first author was at the University of California at Davis and University College London.

We thank Harris Ingle for assistance with data collection and Asher Cohen, Todd Horowitz, Alan Kingstone, and David Lane for helpful comments regarding this manuscript.

http://www.tandf.co.uk/journals/pp/02724987.html DOI:10.1080/02724980143000514

any effort or awareness, and sometimes even when the response is irrelevant to the current goals at hand, such as when a turn is to be made before reaching the second stoplight. Furthermore, these automatic types of response can also occur in the presence of a number of other distractions, such as the sight of a familiar person walking along the street. This series of experiments examines the properties of response channel activation using a modification of the flanker interference paradigm (Eriksen & Eriksen, 1974) under varying conditions of attention and inhibition induced by spatial precueing (Posner & Cohen, 1984).

In a typical flanker interference experiment, subjects respond to a central target flanked by distractors that are congruent, incongruent, or neutral with the target response (Eriksen & Eriksen, 1974). This paradigm has been used to investigate the processing of stimuli within and around the focus of attention (Eriksen & St. James, 1986). Eriksen and Schultz (1979) used this paradigm to demonstrate that the processing of both relevant and irrelevant visual information proceeds in a continuous manner up until a response is emitted. Eriksen and his colleagues subsequently demonstrated, using electrophysiological methods, that interference from irrelevant flankers occurs because of the activation of responses associated with the incongruent flankers (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Eriksen, Coles, Morris, & O'Hara, 1985; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). The flanker task, therefore, has been used not only to demonstrate the properties of visual attention, but also to investigate the electrophysiological as well as the neurological (Cohen, Ivry, Rafal, & Kohn, 1995; Rafal et al., 1996) correlates of response channel activation. In the series of experiments reported here, we used a modified version of this paradigm to determine the roles of spatial attention and inhibition in response channel activation.

To manipulate the locus of attention and inhibition, the flanker task was combined with another standard paradigm used for investigating spatial attention (Posner & Cohen, 1984). Posner and Cohen demonstrated that, following a peripheral change in luminance (a cue), there is an initial facilitation of detecting targets at the cued location succeeded by a subsequent inhibition. In the facilitatory phase of this covert reflexive orienting, reaction times to targets appearing in the cued location are faster than those appearing in uncued locations. Subsequently, in the inhibitory phase of reflexive orienting, the detection of targets that appear in the cued location is slower than that for the uncued location (see also Maylor, 1985; Maylor & Hockey, 1985). Posner and Cohen called the latter inhibitory phenomenon inhibition of return (IOR) and discussed its role in favouring orienting to novel locations.

The main question addressed in this study is whether reflexively and voluntarily summoned orienting processes modulate the amount of interference from distracting elements in the visual scene. It has been suggested that response channel activation may occur outside the focus of attention (Cohen et al., 1995). In that study, two patients with hemispatial neglect were presented with a unilateral flanker that was presented either contralesional or ipsilesional to the target. Stimuli presented in the contralesional hemifield of patients with neglect are usually not detected when attention is directed to an ipsilesional location, or in the case of the study by Cohen et al., toward a target in the centre of the display. The results from that study suggested that response channel activation from the flankers occurred in the neglected, unattended hemifield. A similar type of result was also reported by Audet, Bub, and Lecours (1991).

More recently, however, we found an initial decrease in interference from irrelevant flanking distractors in patients with lesions involving the temporoparietal cortex (Ro, Cohen, Ivry,

& Rafal, 1998). This result suggests that temporoparietal cortex, which has been shown to be involved with spatial attention (Friedrich, Egly, Rafal, & Beck, 1998), is also involved with response channel activation. One interpretation of the modulation of response channel activation in patients with temporoparietal cortex lesions is that it is secondary to the attention deficits produced by these lesions. Alternatively, it may be that the temporoparietal brain region is normally involved with the initial establishment of response codes that are eventually maintained and stored in the lateral prefrontal cortex (Rafal et al., 1996), and that loss of this function reduced response channel activation independent of the attention deficits in these patients. It is unclear, therefore, what role spatial attention may have on the modulation of flanker interference.

The current investigation orthogonally combined the flanker interference and precueing paradigms to determine the effects of spatial attention (i.e., attentional facilitation and IOR) on response channel activation in neurologically normal adults. It might be expected that attention at the flanker location would produce more interference and that IOR at the flanker location would produce less interference from the task-irrelevant flankers. However, as Cohen et al. (1995) showed that response channel activation occurs even when the distractors producing the interference are presented in the contralesional hemifield of patients with hemispatial neglect, it may be that the magnitude of flanker interference would be the same regardless of the locus of attention and inhibition. This series of experiments was conducted to address this issue.

In Experiment 1, subjects responded to whether a central colour patch was red or green. Before the presentation of this target, an exogenous cue was presented to its left or right. When the central colour patch appeared, a flanking colour patch briefly appeared at the same time either in the cued (facilitated or inhibited) location or on the opposite side. The colour of this flanker could be congruent or incongruent with respect to the target. Experiment 2 examined the effectiveness of the exogenous cues by introducing occasional probes at the locations of the cues. In Experiment 3, central arrowhead cues were used to deploy voluntary attention to the flanker locations in order to determine the magnitude of interference produced by endogenously attended or unattended flankers. Experiment 4 used a peripheral report task; the targets were either cued or uncued, and the distractors were always presented centrally at fixation.

General method

Apparatus

All of the experiments were conducted on an IBM-compatible personal computer connected to a NEC Multisync video graphics array (VGA) stimulus monitor. The timing of the visual displays was controlled by the vertical synchronization of the stimulus monitor at 16.67-ms intervals (60 Hz). Millisecond timing, used to obtain response latencies, was achieved by setting the 8253 chip of the computer to millisecond ticks. Responses were made on a two-button response pad connected to the gameport adaptor of the computer. Response times were recorded to the nearest millisecond following a button press.

EXPERIMENT 1

Experiment 1 asked whether response channel activation from an irrelevant flanking distractor would be greater when the distractor was presented at an attended location than when it was presented at an unattended or inhibited location. The locus of attention toward or away from the flanking distractor was manipulated, and the differences in the magnitude of interference produced by irrelevant flankers that appeared at attended and inhibited locations were measured. The aim was to determine whether more interference would occur if the flanker appeared at the attended location and whether less interference would occur if the location of the flanker was inhibited.

Method

Subjects

A total of 24 undergraduate students, 20 females and 4 males, participated in this experiment for partial fulfilment of a course requirement. The age range of the participants was 18–34 years with a mean age of 21 years. All subjects reported having normal or corrected-to-normal vision.

Stimuli and procedure

A fixation point, a small grey circle measuring 0.1°, appeared at the start of each trial in the centre of the screen on a black background. After 500 ms, a cue appeared for 100 ms. The cue was a white box, measuring 1.5° of visual angle in the horizontal and vertical directions. The centre of the cue was 3° to the left or right of the central fixation point. The left and right locations were cued with equal probability across the trials, and the cue had no informative value—that is, the flanker was as likely to occur at cued as at uncued locations. A variable stimulus onset asynchrony (SOA) of either 150 or 750 ms elapsed between the onset of the cue and the onset of the target and flanker display. The two cue-to-target and flanker display SOAs were used to examine both facilitation at the early SOA and IOR at the late SOA. The target and flanker both extended 1° in the horizontal and vertical directions and appeared centred over fixation and at the left or right location, respectively. The centre-to-centre distance between the target and flanker was 3°. The peripheral colour patch was presented either to the left or to the right, with equal probability, for 16.7 ms, and the central colour patch was presented until a response was made. The targets and flankers were filled, coloured squares, each of which could be either red or green with equal probability and could also be congruent or incongruent with respect to one another. The flanker appeared equally often in either the cued or the uncued peripheral location (see Figure 1).

The subjects sat 57 cm from the computer monitor in a diffusely lit room and were instructed to respond to the central colour patch by pressing one button on the response pad if the colour patch was red and the other button on the response pad if the colour patch was green. The subjects used the index and middle fingers of their preferred hand to respond. The colour-to-button response mapping was counterbalanced across subjects such that half the subjects pressed the right button for red targets, and the other half of the subjects pressed the right button for green targets. The subjects were instructed to respond as fast and accurately as possible.

On trials with responses faster than 150 ms or slower than 1500 ms, and on trials with an incorrect button press, the computer generated a tone for 500 ms to inform the participant that an error had occurred. All error trials were discarded from the analysis of reaction times (RTs).

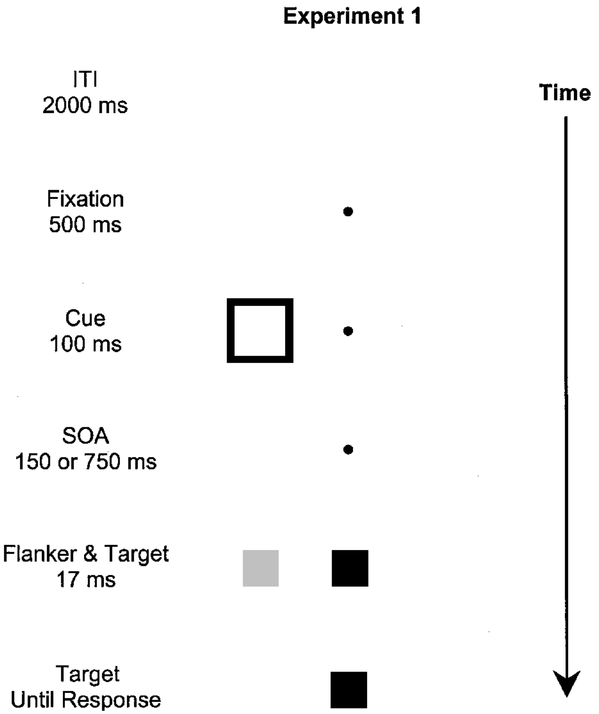

Figure 1. The sequence and timing of events for a typical trial in Experiment 1. This figure depicts the events for a trial in which the flanker appears at the cued location and is incongruent to the target. See text for complete details.

Design

Each subject first completed a practice block of 32 trials. Following the practice block, a total of 24 trials were collected from each subject for each of the eight conditions: 2 (levels of cue: cued vs. uncued) × 2 (levels of flanker congruency: congruent vs. incongruent) × 2 (levels of SOA: short vs. long).

Results

For each subject in each condition, a median RT was computed for the correct responses. An initial four-way analysis of variance (ANOVA) with Response Side × Cue × Flanker Congruency × SOA as the factors was conducted to determine whether the side of the response (same or different from cue, not flanker) had any influence on our measures of main interest. Note that the correspondence of the side of the response with the side of the cue makes the response side the same as the flanker side when the cue is valid and the response side different from the flanker side when the cue is invalid. The main effect of response side was not significant, $F(1, 23) = 2.44$, $MSE = 1551$, $p > .10$, and the only significant interaction with response side was the Response Side × Cue × Flanker congruency, $F(1, 23) = 13.38$, $MSE = 395$, $p < .005$. This was due to larger flanker interference effects when the flanker appeared on the same side as the response regardless of the cue (see Table 1, cf., Diedrichsen, Ivry, Cohen, & Danziger, 2000). This aspect of the results will be discussed further in the General Discussion section. Because

TABLE 1
The congruency effects[a] as a function of the validity of the cue and the cue side–response side compatibility in Experiment 1

	Side compatibility	
	Same	*Different*
Valid	24	18
Invalid	15	40

[a] Incongruent minus congruent, in ms.

none of the other interactions with response side was significant, we collapsed over this factor in the remaining analyses.

The median RTs averaged across subjects for each condition is shown in Table 2. This table contains the data for each of the eight conditions, as well as the error rates and standard deviations (*SD*s). The error trials comprised 3.4% of all trials. For all of the experiments in the current study, error trials were excluded from the RT analyses, and, because of the small number of errors made in these experiments, the error rates will not be discussed further.

The RT data from the correct responses were subjected to a three-way ANOVA with cue, flanker congruency, and SOA as the within-subject factors. There was a significant main effect of flanker congruency reflected by slower responses when the peripheral flankers were incongruent to the target, $F(1, 23) = 20.08$, $MSE = 1311$, $p < .001$. The main effect of SOA was not significant, $F(1, 23) = 2.86$, $MSE = 1457$, $p = .10$, nor was the main effect of cue ($F < 1$). Of particular interest, the magnitude of the flanker congruency effect did not depend upon the cueing manipulation as none of the interactions between cue, congruency, and SOA approached statistical significance (all Fs < 1).

TABLE 2
Mean of the median RTs, *SD*s, and percentage of errors for the different conditions in Experiment 1

		Congruent			*Incongruent*			
SOA[a]	*Cue level*	*RT*[a]	*SD*	*% Error*	*RT*[a]	*SD*	*% Error*	*Incongruent–congruent*[a]
150	Cued	470	76	3.0	494	106	4.9	24
	Uncued	469	86	3.6	495	96	3.1	25
750	Cued	465	88	3.3	483	94	2.8	18
	Uncued	458	99	3.0	484	98	3.3	26

[a] In ms.

Discussion

The flankers used in Experiment 1 produced reliable interference effects; however, the magnitude of this interference was not modulated depending on whether the flanker appeared in the previously cued or uncued location. That is, the flankers at the attended (early-SOA condition) and inhibited (late-SOA condition) locations were equally effective in activating response channels as flankers appearing at the uncued location. These results provide further support for the notion advanced by Cohen et al. (1995) that response channel activation from irrelevant flankers can occur in equal magnitude under attended and unattended conditions.

One could argue, however, that the cueing conditions of this experiment were insufficient in generating covert shifts of attention. Because we did not measure attention at the cued and uncued peripheral locations, it remains unclear whether or not the cues that we used effectively generated reflexive facilitatory orienting and IOR. Yantis and Jonides (1990) and Theeuwes (1991) demonstrated that when attention is endogenously focused on a location prior to an abrupt onset, attention may not be captured by abrupt onsets at unattended locations. Because the parameters in this experiment allowed participants to focus their endogenous attention on the central position of the display (as all targets appeared in this location), it might be that the exogenous cues used here were ineffective in producing reflexive covert orienting responses.

If the cues used did not generate covert shifts of attention, the absence of interactions between spatial cueing and flanker interference in this experiment would not be informative regarding the influence of spatial attention on response channel activation. The next experiment addressed the issue of whether the peripheral cues actually generated covert shifts of reflexive attention. On a proportion of the trials, instead of the colour patch display, a probe appeared at either the cued or the uncued peripheral location. Probe trials, which were randomly intermixed with the flanker trials, were introduced to measure the effectiveness of the cues. Having ensured that the cues generated reflexive orienting responses to their peripheral locations, we measured whether a flanker presented at a facilitated or an inhibited location produced more or less interference than a flanker presented at an uncued location.

EXPERIMENT 2

Experiment 2 was designed to provide further confirmation that response channel activation can occur independently from spatial attention. In Experiment 1, although the cues did not affect response channel activation, the effectiveness of the cues in generating covert orienting responses was not assessed. Here we directly measured the effectiveness of the cues by randomly interleaving "probe" trials in which the RT to detect a peripheral target at the cued or uncued location was measured. This manipulation inherently changes the nature of the attentional state and possibly the effectiveness of the cues and flankers, as participants in this experiment may have adopted a broad focus of attention to include the locations at which flankers were presented because probe targets occasionally appeared at those locations.

Method

Subjects

A total of 20 students, 16 females and 4 males, participated in this experiment for partial fulfilment of a course requirement. The age range of the participants was 18–25 years with a mean age of 19 years. All subjects reported having normal or corrected-to-normal vision.

Stimuli and procedure

The stimuli and procedures of this experiment were identical to those used in Experiment 1 except for the following changes. On a random one third of the trials, a white dot that subtended 0.2° horizontally and vertically appeared 3° from fixation in one of the two peripheral locations (i.e., to the left or right of fixation). On the other two thirds of the trials, a coloured target appeared in the centre and a flanker appeared in one of the peripheral locations as in Experiment 1 (see Figure 2).

On trials with detection targets, which we refer to as probe trials, the probes appeared with equal probability in either the cued or the uncued location. The probes were presented either 150 ms or 750 ms, with equal probability, after the onset of the cue. Subjects responded to the probes by pressing the left button if the probe appeared on the left and the right button if the probe appeared on the right. Responses to target colour patches were performed in the same manner as in Experiment 1, with the same response

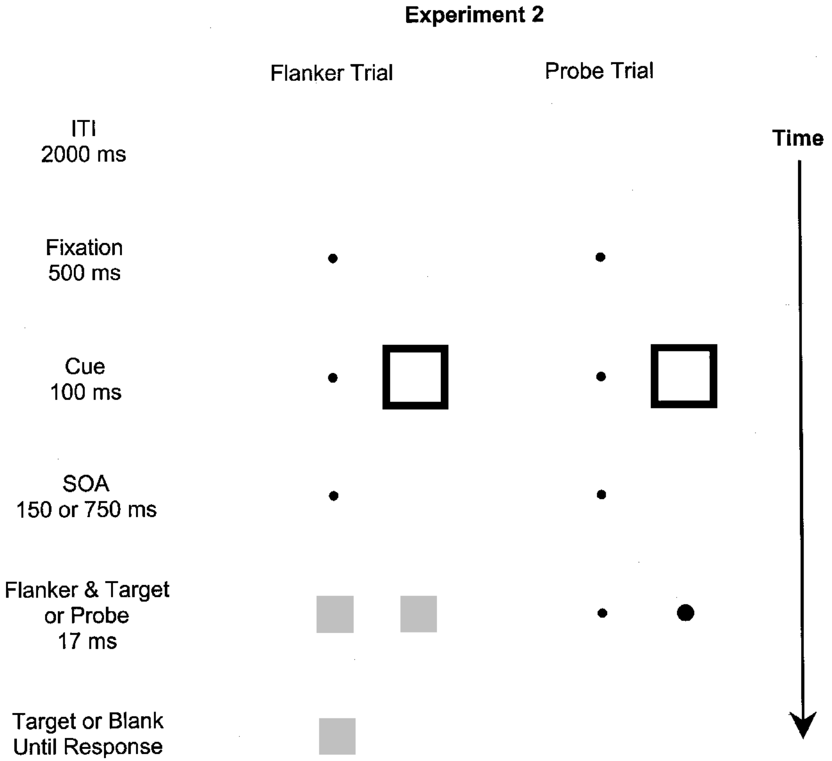

Figure 2. The sequence and timing of events for a typical flanker and target trial (left) and a probe trial (right) in Experiment 2.

buttons as those used in the probe trials. The left button was therefore pressed for either a left detection probe target or a red (or green depending on the colour-to-button response mapping for a given subject) colour patch at fixation, and the right button was pressed for either a right detection probe target or a green (or red) colour patch at fixation. Again, subjects were instructed to respond to all targets as fast and as accurately as possible. Note that subjects could not anticipate whether the target following a cue would be a probe or a central colour patch with flanker because the two types of trial were randomly intermixed. As in Experiment 1, the cue had no informative value; flankers occurred in cued locations equally as often as in uncued locations.

Design

Each subject performed practice trials until it was clear that he or she could accurately perform the task. Reaction times for 96 probe trials and 192 colour patch trials were then collected from each subject. These two types of trial were randomly intermixed. Of the 96 probe trials, the probability of the probe appearing at the cued or uncued location, at each SOA, was equal. Thus, there were 24 trials for each of the four probe trial conditions: 2 (levels of cue: cued vs. uncued) × 2 (levels of SOA: 150 ms vs. 750 ms). For the colour patch trials, 24 trials were presented for each of eight conditions: 2 (levels of cue: cued vs. uncued) × 2 (levels of flanker congruency: congruent vs. incongruent) × 2 (levels of SOA: 150 ms vs. 750 ms).

Results

As before, an initial four-way ANOVA on the median RTs from the correct responses was conducted to determine whether the side of the response (same or different from the cue) had any influence on our measures of main interest. There was again a significant Response Side × Cue × Flanker Congruency interaction, $F(1, 19) = 5.51$, $MSE = 3468$, $p < .05$, due to larger flanker interference effects when the flanker appeared on the same side as the response regardless of the cue (see Table 3, cf., Diedrichsen et al., 2000). We defer discussion of this result until the General Discussion. The main effect of response side ($F < 1$) and all remaining response side interactions were not significant.

The median reaction time for correct responses for each subject in each condition was computed and subjected to two separate ANOVAs. The error rates in this experiment comprised 2.9% of all trials and are shown in Table 4 for each condition.

TABLE 3
The congruency effects[a] as a function of the validity of the cue and the cue side–response side compatibility in Experiment 2

	Side compatibility	
	Same	*Different*
Valid	48	11
Invalid	20	46

[a] Incongruent minus congruent, in ms.

TABLE 4
Mean of the median RTs, *SD*s, and percentage of errors for the different conditions in Experiment 2

		Congruent			*Incongruent*			*Probe*				
SOA[a]	*Cue level*	*RT*[a]	*SD*	*% Error*	*RT*[a]	*SD*	*% Error*	*RT*[a]	*SD*	*% Error*	*Incongruent–congruent*[a]	*Probe diff.*[a]
150	Cued	557	90.1	2.7	602	109	4.8	509	53	1.0	45	
	Uncued	556	82	3.1	599	88	6.5	508	55	2.1	43	-1
750	Cued	569	105	2.7	594	104	3.3	480	44	1.0	25	
	Uncued	578	98	2.7	604	92	4.0	447	45	0.4	26	–33

[a] In ms.

The median RTs from the correct responses to the probe trials, in which only a peripheral dot was presented, are also shown in Table 4. The data from these conditions were subjected to a two-way ANOVA with cue validity and SOA as the two within-subject factors. There was a significant main effect of cue validity from slower RTs for conditions in which the probe appeared in the cued location, $F(1, 19) = 7.12$, $MSE = 843$, $F < .02$. There was also a significant main effect of SOA due to faster RTs in the longer SOA condition, $F(1, 19) = 51.14$, $MSE = 773$, $p < .001$. The cue validity by SOA interaction was also significant, $F(1, 19) = 5.86$, $MSE = 845$, $p < .025$. This interaction was due to a significant delay in responses to probes appearing at the cued location under the long-SOA condition, $t(19) = 3.96$, $MSE = 696$, $p < .005$, but no difference in RTs between the two cue validity conditions at the short SOA ($F < 1$).

The results of the colour patch trials from this experiment more or less replicate those observed in Experiment 1. Correct responses for the eight colour patch conditions (see Table 4) were subjected to an ANOVA, with cue validity, flanker congruency, and SOA as the within-subject factors. There was a significant main effect of congruency due to overall faster RTs when the flanking colour patch was the same colour as the target than when it was the incongruent colour, $F(1, 19) = 38.69$, $MSE = 1254$, $p < .001$. There was a trend for slower RTs at the longer SOA, $F(1, 19) = 3.43$, $MSE = 718$, $F = .076$, and also for a Cue × SOA interaction, $F(1, 19) = 2.91$, $MSE = 450$, $p = .101$. A significant interaction between congruency and SOA was present in the current experiment, $F(1, 19) = 4.89$, $MSE = 640$, $p < .05$. However, the main effect of cue and the other interactions, most importantly the Cue × Congruency × SOA triple interaction, were not significant (all Fs < 1).

Discussion

The results from Experiment 2 provide further support for the claim that response channel activation can occur independent from reflexive covert orienting. The probe trials, in which the appearance of a peripheral dot demanded discrimination of its location, demonstrated that the cues were effective in generating an orienting response eventuating in an inhibition of return at the longer SOA. However, on colour patch trials, flankers presented at the cued location produced no more and no less interference than flankers at the uncued location at either short or long SOAs.

No facilitation was observed, however, in the short SOA condition of this experiment. This may be interpreted as the cues not generating a reflexive orienting response at the early SOA. Alternatively, it could be that at the short SOA the cue triggered both facilitatory and inhibitory processes that each counteracted the other's effect. Recent studies suggest that the task, as well as the temporal properties and relations of the cues and targets, are important in determining whether facilitation or inhibition is observed at a particular cue-to-target SOA (Maruff, Yucel, Danckert, Stuart, & Currie, 1999; Tanaka & Shimojo, 1996; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994). Because the probe task in the current experiment required global localization (cf., Tanaka & Shimojo), and there was no temporal overlap between the cue and target at the short SOA (cf., Maruff et al.; Tassinari et al.), it is perhaps not surprising that no measurable facilitation was observed at the short SOA.

In this dual-task experiment, reaction times were, not surprisingly, slower than those in Experiment 1. The effect of cue–target interval for the colour discrimination task also showed a different pattern from that of Experiment 1. Whereas in Experiment 1 there was a trend for responses to be faster at the long SOA, in Experiment 2 the opposite pattern was observed with faster RTs at the short SOA. By contrast, in the probe task, the opposite effect of SOA was observed with RTs being faster at the longer SOA. The different effects of SOA in this experiment in the two tasks suggests that, in this dual-task situation, participants may have assigned different priorities to the two tasks over the foreperiod: The colour discrimination task being given relatively greater priority at the short SOA and the probe detection task at the longer SOA. The reason that participants may have systematically adopted this strategy for dealing with the dual-task situation is unclear, but it is evident that participants adopted a different response criterion at the short SOA in the discrimination task from that in Experiment 1. Interestingly, the flanker congruency effect (FCE) at the short SOA was larger in this experiment than it was at the longer SOA, or than that for either cue–target interval in Experiment 1. This differential readiness for making a choice response does appear to have influenced response channel activation. This influence of readiness on the FCE is intriguing and deserves further study. However, this effect was independent of spatial attention, which, as was the case in Experiment 1, did not modulate the FCE.

The current experiment clearly demonstrated that IOR did not modulate the flanker interference effect. Although this may be interpreted as arguing against a response- or motor-based account of IOR (e.g., Kingstone & Pratt, 1999; Taylor, 1999; Taylor & Klein, 1998), because response channel activation was uninfluenced by IOR, it is more likely the case that the motor processes affected by IOR and response channel activation are separate. If IOR is a motor-based phenomenon that inhibits responses, it may operate not by inhibiting the activation of response codes, but rather by raising the criteria for initiating actions based on them (Ivanoff & Klein, 2001). Thus, any effect that IOR may have on response time might occur after response channel activation has occurred.

Based on the experiments thus far, it is still not clear whether processes that facilitate attention at the flanker location modulate response channel activation. As the facilitatory effect of reflexive orienting is difficult to measure, in the next experiment we used endogenous cues with a probability manipulation in order to examine the effects of voluntary attention on flanker interference.

EXPERIMENT 3

In Experiment 3, we used a voluntary orienting procedure to address the question of whether or not endogenous attention to a distractor location modulates the magnitude of response channel activation. In Experiment 2, our attempt to probe for the effectiveness of the exogenous cues not only changed the main task, but also confounded the attentional state of the subject (as adding a peripheral probe localization task probably motivated subjects to maintain a broad focus of attention). Experiment 3 provides a further and separate measure of attention on flanker interference, namely the influence of voluntary covert orienting in the absence of reflexive covert orienting on flanker interference.

Method

Subjects

A total of 24 undergraduate students, 14 females and 10 males, participated in this experiment for partial fulfilment of a course requirement. Their ages ranged from 17–38 years with a mean age of 21 years. All subjects reported having normal or corrected-to-normal vision.

Stimuli and procedure

The stimuli and procedure of this experiment were similar to those used in Experiments 1 and 2 except for the following changes. Instead of presenting a cue at one of the peripheral locations, an arrowhead pointing either to the left or to the right served as the cue and was presented in the centre of the screen for 100 ms. The arrowhead (a greater than ">" or less than "<" sign) subtended 0.6° in the horizontal and vertical directions. Following the offset of the central arrowhead cue, 400 ms elapsed prior to the onset of a target display. On a random one third of the trials, an asterisk that subtended 1° horizontally and vertically appeared 3° from fixation in one of the two peripheral locations. On the other two thirds of the trials, a coloured target and flanker appeared as in Experiments 1 and 2 (see Figure 3).

On trials with detection targets, which we again refer to as probes, the probes appeared with 80% probability in the peripheral location indicated by the central arrowhead cue (cued trials) and with 20% probability in the peripheral location opposite that indicated by the central cue (uncued trials). Subjects responded to the probes by pressing the spacebar on a keyboard with their nonpreferred hand. A simple RT, rather than a location discrimination task, was used to ensure that the validity effects observed were due to attentional orienting rather than to response preparation. Responses to target colour patches were performed in the same manner as that in Experiments 1 and 2. Again, subjects were instructed to respond to all targets as fast and as accurately as possible. They were also informed about the predictive value of the cues for probe trials and were told that they could use those cues to speed their reaction times to the probes. However, subjects could not anticipate whether the target following a cue would be a probe or a central colour patch because the two types of trials were randomly intermixed. As in Experiments 1 and 2, the cue had no informative value on colour patch trials, and flankers occurred in cued locations equally as often as in uncued locations.

Design

Each subject performed practice trials until it was clear that he or she could accurately perform the task. Reaction times for 80 probe trials and 160 colour patch trials were then collected from each subject. These two types of trials were randomly intermixed. Of the 80 probe trials, 64 were cued and 16 were

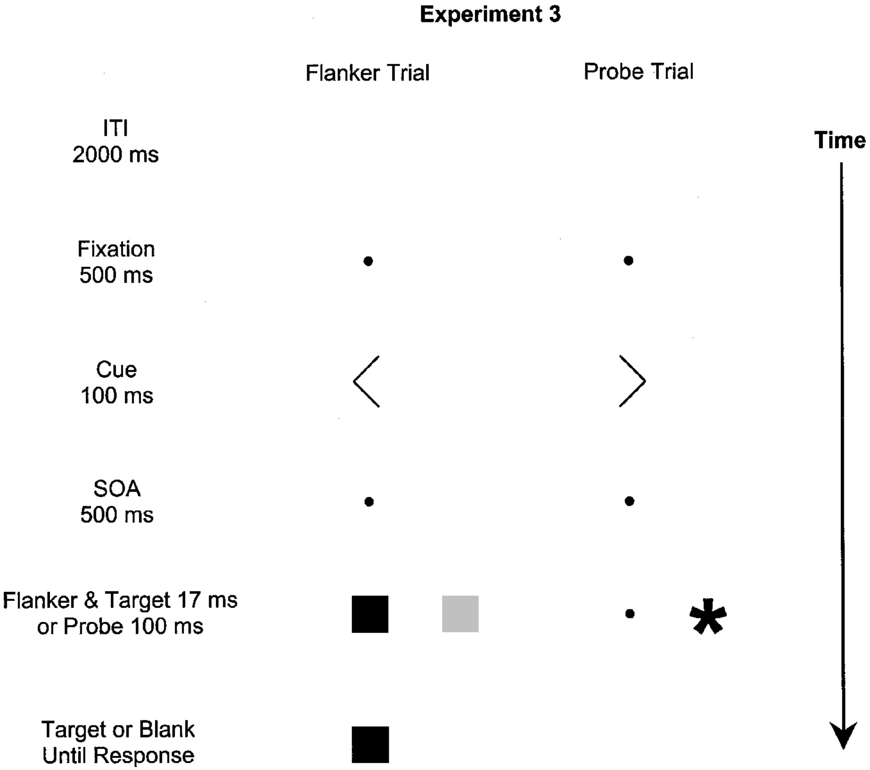

Figure 3. The sequence and timing of events for a typical flanker and target trial (left) and a probe trial (right) in Experiment 3.

uncued. For the colour patch trials, 40 trials were presented for each of four conditions: 2 (levels of cue: cued vs. uncued) × 2 (levels of flanker congruency: congruent vs. incongruent).

Results

An analysis to determine whether the side of the response (same or different from the cue) had any influence on our measures of main interest was initially conducted on the median RTs for correct colour patch responses. As in Experiments 1 and 2, there was a significant Response Side × Cue × Flanker Congruency interaction, $F(1, 23) = 6.41, p < .02$. This again was due to larger flanker interference effects when the flanker appeared on the same side as the response regardless of the cue (see Table 5, cf., Diedrichsen et al., 2000). The main effect of response side ($F < 1$) and the other response side interactions were not significant. The response side factor was not used in the remaining analyses.

The median reaction time for correct responses for each subject in each condition was computed. The error rates in this experiment comprised 2.2% of all trials and are shown in Table 6 for each condition.

Correct responses for the probe trials, in which only an asterisk was presented, were subjected to a t test, with cue validity as the within-subject factor. Response times were

TABLE 5
The congruency effects[a] as a function of the validity of the cue and the cue side-response side compatibility in Experiment 3

	Side compatibility	
	Same	*Different*
Valid	37	21
Invalid	11	29

[a]Incongruent minus congruent, in ms.

significantly faster when the probes appeared in the cued location than when the probes appeared in the uncued location (see Table 6), $t(23) = 2.64$, $MSE = 367$, p < .02. This difference between the two cueing conditions confirmed that attention was endogenously deployed to the location that was cued.

The results of the colour patch trials from this experiment (see Table 6) are similar to those observed in the previous experiments. Correct responses for the colour patch trials were subjected to an ANOVA, with cue validity and flanker congruency as the within-subject factors. There was a main effect of congruency due to overall faster reaction times when the flanking colour patch was the same colour as the target than when it was the incongruent colour, $F(1, 23) = 38.37$, $MSE = 396$, $p < .001$. The main effect of cue and the cue × congruency interaction on the colour patch trials were not significant ($F < 1$).

Discussion

The results from this experiment provide further evidence that response channel activation can occur independently from covert attention. The probe trials in which an asterisk was presented confirmed that the locus of endogenously oriented attention was effectively shifted to the cued location. However, on the colour patch trials, a flanker at the attended location produced no more and no less interference than did flankers at the uncued location. These results are consistent with the results of Experiments 1–2 that demonstrated that response channel activation can occur independently from exogenous attention.

TABLE 6
Mean of the median RTs, *SD*s, and percentage errors for the different conditions in Experiment 3

	Congruent			*Incongruent*			*Probe*				
Cue level	*RT*[a]	*SD*	*% Error*	*RT*[a]	*SD*	*% Error*	*RT*[a]	*SD*	*% Error*	*Incongruent–congruent*	*Probe diff.*[a]
Cued	483	57	2.8	512	57	4.8	493	59	0.4	29	
Uncued	488	60	2.2	510	57	2.5	507	64	0.0	22	14

[a]In ms.

In the next experiment a peripheral report, colour discrimination task was used to provide further evidence that response channel activation is independent from attention. Note that unlike Experiments 1–3, Experiment 4 asks whether attention to the target rather than to the flanker location makes it more (or less) vulnerable to interference from competing response codes activated by a central distractor.

EXPERIMENT 4

Experiment 4 was conducted to provide further evidence that spatial attention has no influence on response channel activation. In this experiment, unlike Experiments 1–3, we are able to measure the effectiveness of the cues on the same trials as those in which interference from the central distractors is being measured. Experiment 4 is identical in all respects to Experiment 1 with two exceptions: Subjects in Experiment 4 responded to the colour of the briefly flashed peripheral colour patch instead of that of the central one, and box markers were introduced to demarcate the possible target locations. Note that with this new task it is now the target, not the distractor, that is cued or uncued. Furthermore, the location of the target is uncertain whereas the location of the distractor is anchored at fixation. This manipulation allowed us to directly examine the effectiveness of the cues in reflexively generating facilitatory and inhibitory effects at the cued (and now target) location under conditions in which subjects could not filter out those locations for the entire experiment. Furthermore, the interference produced by the central distractor under conditions of facilitated and inhibited target responses could be observed. If attention is more focused on the target at the expense of other locations, then the target might be expected to be less vulnerable to interference from distractors.

Method

Subjects

A total of 24 students, 15 females and 9 males, participated in this experiment for partial fulfilment of a course requirement. The age range of the participants was 18-30 years with a mean age of 21 years. All subjects reported having normal or corrected-to-normal vision.

Stimuli and procedure

The stimuli were exactly the same as those in Experiment 1 with the addition of three box markers, which were unfilled squares measuring 1.5° of visual angle in the horizontal and vertical directions. The box markers were presented and remained on the display monitor throughout the experiment. The middle box was presented in the centre of the monitor with one box to its left and one box to its right. The centre-to-centre distance between the middle box and each of the peripheral boxes was 3°. The boxes were grey in colour and were presented on a black background. The procedure was also identical to that of Experiment 1 with the exception that subjects now responded to the briefly presented peripheral colour patch instead of the central one.

TABLE 7
Mean of the median RTs, *SD*s, and percentage of errors for the different conditions in Experiment 4

		Congruent			*Incongruent*				*Uncued–cued*[a]	
SOA[a]	*Cue level*	*RT*[a]	*SD*	*% Error*	*RT*[a]	*SD*	*% Error*	*Incongruent – congruent*[a]	*Congruent*	*Incongruent*
150	Cued	564	100.7	6.2	603	102.6	4.7	39		
	Uncued	584	107.3	6.2	628	123.8	6.1	44	20	25
750	Cued	581	119.5	3.0	619	99.0	3.6	38		
	Uncued	564	112.7	4.7	590	100.8	4.5	26	–17	–29

[a] In ms.

Results

An initial analysis involving response side was conducted, which showed no significant main effect of this factor or any interactions with it. The remaining analyses were conducted without this factor. The median reaction times were computed for each subject in each condition. Errors occurred on 4.9% of the trials and are broken down by condition in Table 7. The data from the correct trials are also presented in Table 7. As in Experiment 3, the error rates were low and will not be discussed further.

As can be seen in Table 7, there was a biphasic influence of the cue across the two SOAs. This biphasic effect of the cue demonstrates that the cue used in these experiments was effective in producing facilitatory and inhibitory effects in this peripheral report task. The biphasic pattern of RTs was statistically confirmed in an ANOVA by a significant cue by SOA interaction, $F(1, 23) = 15.01$, $MSE = 1620$, $p < .005$. Comparisons were made to determine the source of this interaction and revealed that there was a significant facilitation at the cued location at the early SOA, $t(23) = 2.29$, $MSE = 1146$, $p < .05$, and a significant IOR for discrimination between colours at the long SOA, $t(23) = 4.09$, $MSE = 367$, $p < .001$.

This experiment also showed a significant effect of flanker congruency produced by slower responses when the distractors (the central colour patch) were incongruent than when they were congruent, $F(1, 23) = 33.97$, $MSE = 1929$, $p < .001$. In contrast to Experiment 1, the main effect of SOA was not significant ($F < 1$). The Cue × Congruency × SOA triple interaction was also not significant ($F < 1$), indicating the independence between cueing (facilitation and IOR) and flanker effects. None of the remaining effects or interactions were significant (all Fs < 1).

Discussion

The results from this experiment demonstrate that the cues used were effective in generating facilitatory and inhibitory effects. Furthermore, the results also demonstrate that IOR is manifest in a colour discrimination identity task. The question of whether or not IOR occurs in a discrimination task has been controversial, and the exact conditions that produce IOR in discrimination tasks is unclear. For example, some investigators report that IOR does not occur in discrimination tasks (Egly, Rafal, & Henik, 1992; Terry, Valdes, & Neill, 1994), whereas others report that IOR does occur when a discrimination is required, but only under certain conditions (Cheal, Chastain, & Lyon, 1998; Egly, Rafal, Henik, & Berger, in press; Lupianez, Milan, Tornay, Madrid, & Tudela, 1997; Pratt, 1995; Pratt, Kingstone, & Khoe, 1997; Tanaka & Shimojo, 1996). The current results provide further evidence that IOR is present in identity-based discrimination tasks and are consistent with recent reports demonstrating similar findings (Egly et al., in press; Lupianez et al., 1997; Pratt et al., 1997).

Of particular interest is the independence between the influences of the cue and the influences of the central distractor. The results from this study demonstrate that when attention is oriented towards a target location prior to its appearance, interference from distractors in other locations is as effective in activating response channels as it is when attention is not oriented to the target location. These results provide further support for the notion advanced by Cohen et al. (1995) that response channel activation from irrelevant flankers occurs in equal magnitude under attended as under unattended conditions. Additionally, the magnitude of distractor interference under conditions where the target location is inhibited appears to be equal in magnitude to that observed under uninhibited target location conditions (750-ms SOA trials).

GENERAL DISCUSSION

The results from the current series of experiments showed that the focus of attention, when reflexively (Experiments 1, 2, and 4) or voluntarily (Experiment 3) summoned, did not modulate the amount of response channel activation produced by irrelevant distractors. The independence of flanker interference and attention demonstrated here in neurologically normal individuals converges with the findings obtained by Cohen et al. (1995) in patients with neglect. The neglect patients in the Cohen et al. study showed no difference in interference from flankers that were presented contralesionally as compared to ipsilesionally. The current results generalize that finding by showing that in neurologically intact participants, the magnitude of distractor interference was uninfluenced by the locus of attention. Furthermore, the present study demonstrated that even when the distractor locations were inhibited, the magnitude of flanker interference was unchanged.

In the three experiments that assessed the effects of spatial attention on response channel with a unilateral peripheral flanker, we consistently measured greater response channel activation if the flanker was on the same side as the button press response (cf., Diedrichsen et al., 2000). Diedrichsen et al. suggested that this correspondence effect might be due to perceptual grouping of the target and flanker on congruent trials, resulting in a Simon-like effect. An alternative explanation was also considered: that the motor response initiated a shift of attention and that, when the flanker was at the location toward which attention had been shifted, the effect of attention amplified the activation of its response code and, thus, an augmented FCE. In one experiment they provided evidence that attention was shifted toward the side of the response. That experiment used a colour-patch discrimination task in the centre and a second task of letter discrimination for letters briefly appearing on the left and right sides. They found under some conditions that letter discrimination was better for letters appearing on the same side than for those appearing on the response side. Our experiments show that attention shifting does not modulate the flanker interference effect. This suggests that the perceptual-grouping hypothesis better accounts for this effect and that the attention effect that Diedrichsen et al. measured did not directly modulate the magnitude of the flanker interference effect.

There have been previous reports demonstrating that precueing the location of an upcoming target reduces the interference that a distractor generates (Paquet & Lortie, 1990; Yantis & Johnston, 1990). Paquet and Lortie showed that the use of a fixation point, which is followed by a central target letter (and peripheral flankers), reduces the magnitude of flanker interference as compared to conditions in which no fixation point was used. Yantis and Johnston demonstrated that precueing a target location with completely or highly predictive peripheral or central arrowhead cues also decreases the interference from surrounding letters. This decrease in interference in the Yantis and Johnston study may have been, like the Paquet and Lortie study, due to the location information provided by the precues. Other experiments that we have conducted, which manipulated the presence or absence of markers for target and flanker locations, also demonstrated the importance of location information in the flanker task (Ro, Machado, Kanwisher, & Rafal, unpublished observations). In these other experiments, however, we demonstrated that although location markers reduce the magnitude of distractor interference by making the location of the target and flanker more clearly defined and less subject to confusion, unpredictive exogenous cues at the location of the flankers did not. Thus, location uncertainty of targets and distractors may modulate the amount of interference generated by distractors, but spatial attention does not.

It is important to note that the flanker discrimination task used here was one with a low perceptual load. Lavie (Lavie, 1995; Lavie & Tsal, 1994) showed that the locus of attentional selection in a flanker task is contingent upon the perceptual load. As late selection can occur under conditions of low perceptual load, as in the task used here, the lack of an effect of covert orienting of attention on distractor interference is consistent with Lavie's framework.[1] Under conditions of higher perceptual load, in which, according to Lavie, early selection is more likely, covert orienting may influence distractor interference (cf., Fuentes, Vivas, & Humphreys, 1999). We are now conducting experiments that manipulate location uncertainty and perceptual load to explore these questions.

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[1] As in none of our experiments were we able to directly demonstrate early reflexive orienting during a flanker interference task with central report, it is still an open question as to whether peripheral flanker interference interacts with this facilitatory component of reflexive orienting. However, Experiment 4 demonstrates that when a target is facilitated, a flanking distractor at fixation does not change its magnitude of response channel activation.

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Original manuscript received 19 May 2000
Accepted revision received 20 June 2001