

Inhibitory Tagging of Stimulus Properties in Inhibition of Return: Effects on Semantic Priming and Flanker Interference

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In this study we examine the level at which inhibition of return (IOR) affects the processing of visual stimuli. Experiments 1 and 2 examined the effect of IOR on semantic priming. Experiments 3 and 4 examined the effect on flanker interference. In both cases IOR could reverse the standard effects. We suggest that when attention is drawn away from a location, there is temporary inhibitory tagging of stimuli that are presented there. This tagging extends to the semantic and response-relevant properties of stimuli, helping to bias attention away from old and towards new events. Due to inhibitory tagging, responses to new targets can be slowed down when targets are semantically related (Experiments 1 and 2) or require the same response (Experiments 3 and 4) as inhibited primes.

Selective processing of objects in the visual environment is necessary for organized behaviour, but despite over thirty years of study, controversy remains about how selective processing occurs in the brain (see, e.g. Broadbent, 1971; Desimone & Duncan, 1995; Posner & Petersen, 1990; Schneider, 1995; Watson & Humphreys, 1997, for reviews). Recent work indicates that one mechanism of selection involves the inhibition of previously attended locations (Maylor, 1985; Posner & Cohen, 1984; Rafal, Calabresi, Brennan, & Sciolto, 1989) or objects (Gibson & Egeth, 1994; Tipper, Weaver, Jerreat, & Burak, 1994). If internal representations of previously attended objects or their locations are inhibited, these objects and/or locations will lose out in competition for selection with new objects or locations, and attention will be biased away from previously attended objects and/or locations. This biasing of attention away from old objects and locations

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has been termed “inhibition of return” (IOR) (Posner & Cohen, 1984). To illustrate, in a typical IOR paradigm participants are presented with three boxes, one in the centre (the fixation box) and two in the periphery. Subsequently, one of the peripheral boxes brightens briefly (the cue), and after varying intervals a target appears. The target can be presented either at fixation or at one of the two peripheral locations. Importantly, the peripheral cue (a brief luminance increment) is not informative about the upcoming target location. Results show that at short cue–target intervals (generally less than 300 msec, target detection responses are faster when the target is presented at the cued location than when it is presented at the uncued location (a facilitatory effect). Facilitation at short intervals is thought to occur because attention is oriented automatically to the brightened box, improving target detection. However, with intervals longer than 300 msec the facilitatory effect typically becomes inhibitory (Posner & Cohen, 1984). Target detection responses are now slower at the cued location than at the uncued location; there is inhibition of return (IOR). With long intervals, attention presumably returns to fixation, as the cue does not provide any relevant information about the target location. (The fixation position can be further favoured if a central cue is included between the peripheral cue and the target.) To date, studies of IOR have focused on two main issues. One is concerned with the coordinates of the representations subject to inhibition. For instance, experiments have attempted to define whether inhibited representations are bound to locations or whether they are object-centred (e.g. Gibson & Egeth, 1994; Tipper et al., 1994). Current evidence suggests that both location-based and object-based effects can occur. The second issue is concerned with the nature of the phenomenon.

Some authors have assumed that IOR reflects a bias in responding rather than in perceptual attention (see Klein & Taylor, 1994, for a review). Thus, IOR is mainly observed when participants are told to detect a target, or when a choice response is based on location. In contrast, IOR has not been observed in a variety of tasks that demand discriminative responses rather than simple target detection, such as temporal order judgements (e.g. Posner, Rafal, Choate, & Vaughan, 1985), letter discrimination (e.g. Terry, Valdes, & Neill, 1994), or illusory line motion judgements (e.g. Schmidt, 1996; but see Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Pratt, 1995, Pratt, Kingstone, & Khoe, 1997, for evidence of IOR in some discrimination tasks).

An alternative view is that IOR is a truly attentional perceptual phenomenon (Reuter-Lorenz, Jha, & Rosenquist, 1996). Reuter-Lorenz et al. (1996) pointed out that if IOR is an attentional effect, its magnitude should be affected by the same factors that usually affect other attentional effects (e.g. costs and benefits from predictive cues). They observed that IOR is greater for visual than for auditory targets, and also greater for low-intensity than for high-intensity targets, just as is observed in studies of attention using predictive cues (Posner, 1978).

A different way of assessing the attentional or otherwise nature of IOR is to look at whether it affects particular levels of stimulus processing (Fuentes, Vivas, & Humphreys, *in press*). In studies of attention, a traditional question is whether attention affects early or late levels of processing, with the distinction between early and late levels usually based on whether (a) attention affects access to stored knowledge by stimuli, and (b) whether attention prevents stimuli from activating associated responses (see Eriksen, 1995, for a recent review). This traditional question has not previously been addressed by studies of

IOR. Although it might be assumed that IOR operating on location-coded representations produces a form of early selection, or that operating on object-centred representations produces a form of late-selection, this can be queried (e.g. Müller & Humphreys, 1991). For example, it is possible that IOR on location-coded representations prevents activated stored knowledge corresponding to particular locations from becoming linked to response processes, rather than limiting the activation of stored knowledge per se. Or, alternatively, IOR on object-centred representations might affect target processing at different levels depending on the task.

In the present research we present four experiments aimed at elucidating the level(s) of processing at which IOR is applied. To do this, we combined procedures that have been found to elicit IOR with tasks that have previously been shown to tap specific levels of information processing. We asked whether IOR influences access to the levels of processing revealed in the tasks. In Experiments 1 and 2, we combined IOR procedures with a semantic priming paradigm (e.g. Meyer & Schvaneveldt, 1971; Neely, 1991) to examine whether IOR influences the efficiency with which stimuli contact their stored representations in memory to produce priming. If IOR affects an early stage of processing, it is possible that access to semantic knowledge is either prevented or delayed for stimuli that fall in inhibited locations. In Experiments 3 and 4 we combined IOR procedures with a task sensitive to response competition between stimuli—the “flanker” task (Eriksen, 1995; Eriksen & Eriksen, 1974). In this study we asked whether the efficiency of response activation is affected by IOR. Again, if IOR influences the early processing of stimuli, then flanker interference may be reduced when flankers fall in inhibited locations.

EXPERIMENT 1

Semantic Priming with Prime–Target SOA of 800 Msec

In Experiment 1a we assessed whether words presented at putatively inhibited locations contacted their stored representations as efficiently as did words at non-inhibited locations. Participants made lexical decisions to words and non-words presented at one of two peripheral locations. Prior to the words appearing, participants were cued to attend to one of the peripheral locations, and then attention was returned to a central location before the words appeared. There were two letter strings on each trial, and we assessed the “priming” effect of the first string (the prime) on lexical decision times to the second string (the target). The sequence of events on a typical trial is shown in Figure 1.

Experiment 1b was a control study, to test for IOR on word primes. In that experiment, no second strings were presented, and participants made a simple detection response as soon as possible after the prime string was presented.

Method

Participants

Thirty-four and twenty undergraduates from the University of Almería participated in Experiments 1a and 1b, respectively. They received course credit for their participation, and all of them had normal or corrected-to-normal vision.

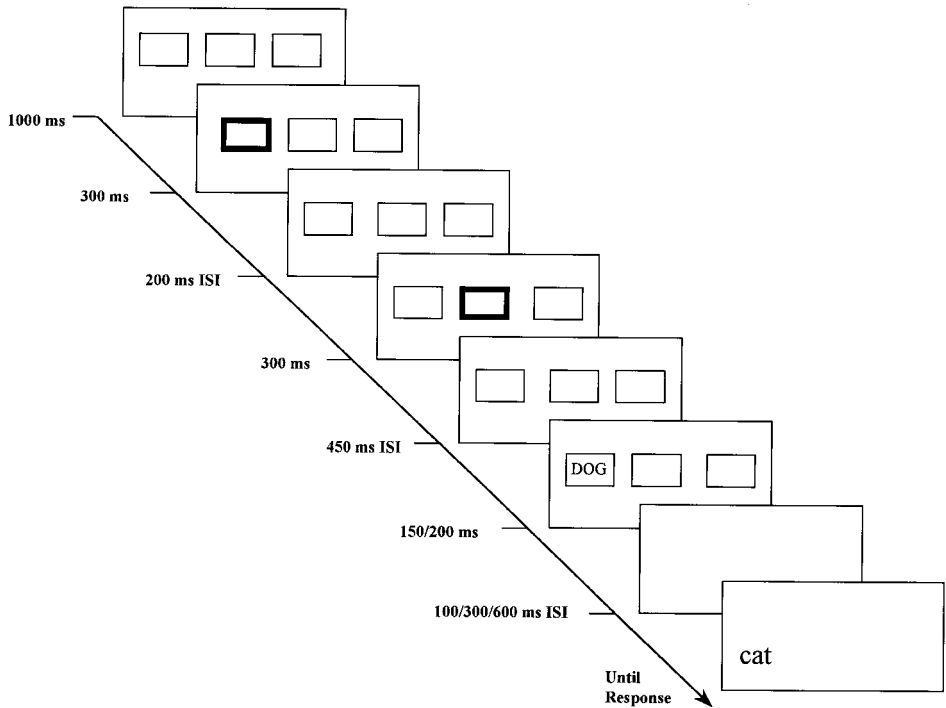


FIG. 1. Sequence of events and exposure durations of stimuli in Experiments 1 and 2. SOAs were 800 msec (Experiment 1), 500 msec (Experiment 2a), and 250 msec (Experiment 2b).

Procedure

In Experiment 1a, the procedure was as follows. A central fixation cross appeared first for 500 msec, followed by three white boxes for 1000 msec. One of the peripheral boxes then changed colour, to red, for 300 msec (the peripheral cue). Subsequently, the three boxes changed back to white for 200 msec, after which the central box changed to red for 300 msec (the central cue). After the central cue, there was a 450-msec interval with the three boxes in white again, followed by the prime word appearing randomly inside one of the peripheral boxes for 200 msec. Thus, the cue–prime SOA was 1250 msec. The target word or nonword appeared 600 msec after the offset of both the prime word and the three boxes just below the prime position and remained on until response (lexical decision in this experiment).

In Experiment 1b the procedure was the same, except that no target stimuli were presented and there were two blank intervals from the central cue to the prime word: 150 and 450 msec (producing SOA values of 950 msec and 1250 msec, respectively), presented mixed within each block of trials in order to prevent anticipations.

Stimuli and Design

Stimuli were presented on a colour monitor (VGA) of an IBM/PC-compatible computer, and responses were recorded via the computer keyboard. The boxes subtended viewing angles of $5.4^\circ \times 1.3^\circ$, when seen from the viewing distance of 60 cm. The inner sides of the two peripheral boxes were

each located 4.9° from fixation. The prime was shown in capital letters, and it appeared randomly either at the cued or at the uncued location inside one of the peripheral boxes, 6.6° from fixation. The peripheral cues were not informative about prime location, an essential condition to observe IOR effects. In Experiment 1a, the target appeared in lower case, and it was presented just below the position of the prime until participants made a lexical decision (they pressed one key if the prime was a word, another key if it was a nonword). Primes and targets were either semantically related or unrelated. Four prime–target pairs were used for the related condition: DOG–*cat*, HAND–*finger*, BREAD–*wine*, and SEA–*river*. In the unrelated condition each prime was paired with an unrelated target (e.g. DOG–*finger*), so that each prime word was followed by all target words from the remaining pairs. In all conditions there was the same proportion of related and unrelated trials. Target nonwords were formed by changing a single letter of the corresponding target word. Target nonwords were preceded by the same prime words as were target words. All this was done to prevent participants from anticipating target words, and within these, related targets.

Participants were given one practice block of 64 trials, followed by one experimental block of 192 trials. In the experimental block, there were 96 trials in which targets were words and 96 trials in which they were nonwords. Also, within each set of 96 trials there were 48 trials for the related condition and 48 for the unrelated condition. Finally, on half the trials, prime words were presented at the cued location, on the other half, at the uncued location.

In Experiment 1b only primes were presented, and participants were told to make simple detection responses by pressing the space bar on the keyboard. Participants were given three blocks of 64 trials (the first block was practice).

Results

Experiment 1a

The mean of the median correction reaction times (RTs) and the percentage errors to targets separately for words and nonwords, are shown in Table 1. Target non-words did not show any reliable result for either RTs or errors.

Results for target words showed that RTs were shorter in the related than in the unrelated condition, $F(1, 33) = 15.6, p < .001$, and in the cued than in the uncued prime location, $F(1, 33) = 10.9, p < .01$. The Prime Location \times Relatedness interaction was not reliable ($F < 1$). We did not find any reliable effect for error data.

The cued location produced a benefit in RTs to target words in this experiment. It means that the advantage of the cue could extend to adjacent regions just below the prime location, where only the target could be presented. However, as this result was not observed with target non-words and was not replicated in the following experiments, we do not discuss it any further.

Experiment 1b

Mean of median detection times were slower for words in the cued location than for those in the uncued location—321 msec versus 287 msec, $F(1, 19) = 34.7, p < .001$. This IOR effect held across both cue–prime intervals: the RTs to primes in cued and uncued locations were 347 msec versus 309 msec, and 295 msec versus 265 msec, for the 950 and 1250 cue–prime SOAs, respectively.

TABLE 1
 Mean of Median Reaction Times and Percentage of Errors as a Function of
 Location and Relatedness

Location	<i>Experiment 1a</i>				<i>Experiment 2a</i>				<i>Experiment 2b</i>			
	<i>Related</i>		<i>Unrelated</i>		<i>Related</i>		<i>Unrelated</i>		<i>Related</i>		<i>Unrelated</i>	
	Mean	Errors	Mean	Errors	Mean	Errors	Mean	Errors	Mean	Errors	Mean	Errors
Words												
cued	605	2.6	620	3.1	582	1.9	615	4.2	600	3.0	583	2.6
uncued	620	2.8	639	3.9	589	2.0	617	3.0	588	3.6	605	3.0
Nonwords												
cued	645	2.9	644	2.5	633	2.8	626	2.3	644	4.8	646	3.6
uncued	659	4.0	647	2.6	618	3.2	625	2.8	634	5.4	634	3.8

Discussion

The results of Experiment 1b show that there was an IOR effect: RTs to detect primes at the location first cued were slowed relative to when primes occurred at uncued locations. IOR was maintained across the two presentation SOAs we examined. The longer cue–prime SOA in Experiment 1b matched the equivalent SOA in Experiment 1a, so there is evidence that inhibition was applied to primes at cued locations at the time they appeared in the priming study, Experiment 1a. Nevertheless, priming from inhibited primes (at cued locations) was as large as that from non-inhibited primes (at uncued locations). This suggests that IOR did not affect the efficiency with which primes contacted their stored representations and generated semantic priming at the present prime–target interval.

However, an alternative account can be proposed.¹ It may be that IOR *does* affect the efficiency with which stimuli contact their stored representations, but, with the relatively long intervals between primes and targets that were used, there is still sufficient time for primes to activate stored knowledge fully; once stored knowledge is fully activated, maximal semantic priming occurs. In Experiment 1a, the interval from the onset of the prime to that of the target (SOA) was 800 msec—200 msec prime plus 600 msec inter-stimulus interval (ISI)—which may have been sufficiently long for primes to activate stored knowledge fully, even if access to that stored knowledge was slowed down by IOR. In Experiment 2, we used the same procedure as in Experiment 1a, except that shorter ISIs were employed between prime and target. In Experiment 2a the interval between prime onset and target onset (SOA) was 500 msec, and in Experiment 2b it was 250 msec. Previous

¹ We want to acknowledge Jon Driver and the reviewers for suggesting this.

research has shown that semantic priming occurs in an automatic fashion when there is only a 250-msec SOA between words (cf. Neely, 1977). The cue–prime SOA was 1250 msec as in Experiment 1a.

EXPERIMENT 2

Semantic Priming with Shorter SOAs

Experiment 2a: 500-msec SOA

Method

The method was the same as in Experiment 1a, except that there was a SOA of 500 msec between primes and targets. The cue–prime SOA was as before (1250 msec). There were 18 participants from the Universidad de Almería, who received course credit for participation. All had either normal or corrected-to-normal vision.

Results

The mean of the median correct RTs, and the percentage errors for target responses (word/ nonword) are given in Table 1. As in Experiment 1a, analysis of target nonwords did not produce any reliable effect.

There were faster RTs to target words preceded by related primes than those preceded by unrelated primes—586 msec versus 616 msec, $F(1, 17) = 20.96$, $p < .001$. The main effect of prime location and the Prime Location \times Relatedness interaction were not reliable (both $F_s < 1$).

Similar trends occurred in the error data. There was a marginal effect of priming condition, $F(1, 17) = 3.77$, $p < .07$, with errors being lower in the related than in the unrelated condition (1.97% vs. 3.59%, overall). Neither the effects of prime location nor the Prime Location \times Condition interaction were reliable (both $F_s < 1$).

Discussion

As in Experiment 1a, there was a reliable effect of semantic priming, even though primes were presented at cued locations. Note that Experiment 1b had found IOR at the cued location for primes at the same cue–prime SOA. The priming effect was similar when primes were presented at inhibited or at non-inhibited locations—that is, there was no evidence of semantic priming being affected by IOR.

Experiment 2b: 250-msec SOA

In Experiment 2b we repeated the conditions of the previous experiments and introduced two important modifications: (a) we further shortened the prime–target SOA, to 250 msec; and (b) we presented the prime words for 150 msec. The two changes were introduced to make it less likely that semantic priming would reach ceiling, thus allowing us to capture any effect of IOR on semantic processing.

Method

The method was the same as in Experiment 1a, except that the prime–target SOA was reduced to 250 msec and the prime word duration was only 150 msec. The cue–prime SOA was 1250 msec, as before. There were 21 participants from the Universidad de Almería, who received course credit for participation. All had either normal or corrected-to-normal vision.

Results

The mean of the median correct RTs and the percentage of errors for target responses (word/ nonword) are given in Table 1. As in the previous experiments, analysis of target nonwords did not show any reliable result. Analysis of target words showed that the main effects of prime location and relatedness were not reliable (both $F_s < 1$). However, relatedness now interacted with prime location, $F(1, 20) = 9.6, p < .01$, indicating that IOR affected the processing of primes. When primes were presented at the uncued location, RTs were faster for targets preceded by related primes than for those preceded by unrelated primes, $F(1, 20) = 5.0, p < .05$, revealing the usual semantic priming effect. In contrast, when primes were presented at the cued location, RTs were now slower for targets preceded by related primes, $F(1, 20) = 5.56, p < .05$. The error data did now show any reliable effects (all $F_s < 1$).

EXPERIMENT 2a versus 2b

An additional three-way mixed ANOVA was conducted with data from Experiments 2a and 2b. The analysis of RTs showed no main effects of either experiment or prime location ($F_s < 1$). The main effect of relatedness was reliable, $F(1, 37) = 12.03, p < .01$. Overall, related targets produced shorter RTs than did unrelated targets (590 msec versus 604 msec). However, this difference was observed only in Experiment 2a (586 msec versus 616 msec); in Experiment 2b there were no differences at all (594 msec with both related and unrelated targets), a change in outcome that was supported by the reliable Experiment \times Relatedness interaction, $F(1, 37) = 13.9, p < .001$. Most important, that interaction was qualified by the reliable second-order Experiment \times Prime Location \times Relatedness interaction, $F(1, 37) = 3.97, p = .05$. The overall lack of difference between related and unrelated targets in Experiment 2b was due to the negative effect found when targets were presented at the cued location (-17 msec), combined with the positive effect found when presented at the uncued location (17 msec).

Discussion

As in the previous experiments, we observed semantic priming from stimuli at non-inhibited (uncued) locations. However, at the short SOA of Experiment 2b, a quite different result emerged at the cued (inhibited) location. Unlike in Experiments 1a and 2a, there was negative rather than positive priming from semantically related words. This finding is consistent with the idea that IOR exerts only a temporary influence on priming, so that its effects cannot be detected unless the prime–target SOA is sufficiently short. Interestingly, IOR did not simply lead to a decrease in the magnitude of semantic priming,

as might be expected if there was modulation of the early processing of stimulus information, so that there was less semantic activation over trials; instead, IOR *reversed* the effect. The size of negative semantic priming at the cued location was also at least the same size as the positive semantic priming effect at the uncued location. Thus, there are no grounds to say that IOR decreased the efficiency with which prime words contacted semantic memory.

There are two possible reasons for this. One is that there is inhibition of all the properties of stimuli that fall at a location subject to IOR. Thus, as a word at that location is processed, there is inhibition of its semantic representation. Due to spreading inhibition, the semantic representations of related words also become inhibited, with the result that RTs to related words are slowed. One problem for this account is that the negative effect of semantic priming at a short SOA became a positive effect at longer SOAs (Experiments 1a and 2a). It is possible that this reversal is due to the 50-msec difference in prime exposures across the studies (e.g. if inhibition decayed rapidly and there was then time to re-activate prime representations), but we suggest that this is unlikely. We also do not know of any facilitatory “rebound” mechanism that should lead to the activation of prime representations after they have been inhibited (cf. Houghton, Tipper, Weaver, & Shore, 1996, who argue for an *inhibitory* rebound mechanism).

A second possibility is that IOR does not modulate the activation of semantic representations by primes per se, but, rather, it gives any activated information an inhibitory tag with respect to response process. Primes activate their semantic representations, but outputs from these representations to decision-making processes are inhibited. A spread of these inhibitory tags to related representations would then slow responses to targets that are semantically related to primes. Now, if inhibitory tagging has a relatively short time course, this process will decay whilst leaving the semantic representations of primes still active to facilitate decisions to related targets (as we found).

EXPERIMENT 3 IOR and the “Flanker” Task

In Experiment 3 we sought to test the generality of the peculiar reversed priming effect found in the previous experiment, on a procedure known to be sensitive to response competition between stimuli: the “flanker” task (Eriksen & Eriksen, 1974). In this task participants have to make a choice response to a letter or number, which can be flanked by letter or number distractors. Reaction times are slowed when the distractors are associated with the opposite response to the target relative to when they are associated with the same response (in the incompatible and compatible conditions, respectively—see Eriksen, 1995, for a review). If IOR affects the ease with which stimuli contact their specific responses, as we assumed from the previous semantic priming experiments, a reversal of the standard flanker effect is then expected when distractors are presented at cued locations.

To test this prediction, the flanker task was combined with the IOR procedure. The sequence of events is shown in Figure 2.

Participants performed one of two intermingled tasks. In the *detection* task (on 75% of the trials), they responded with a keypress to the presence of a letter or number (B or 5) at

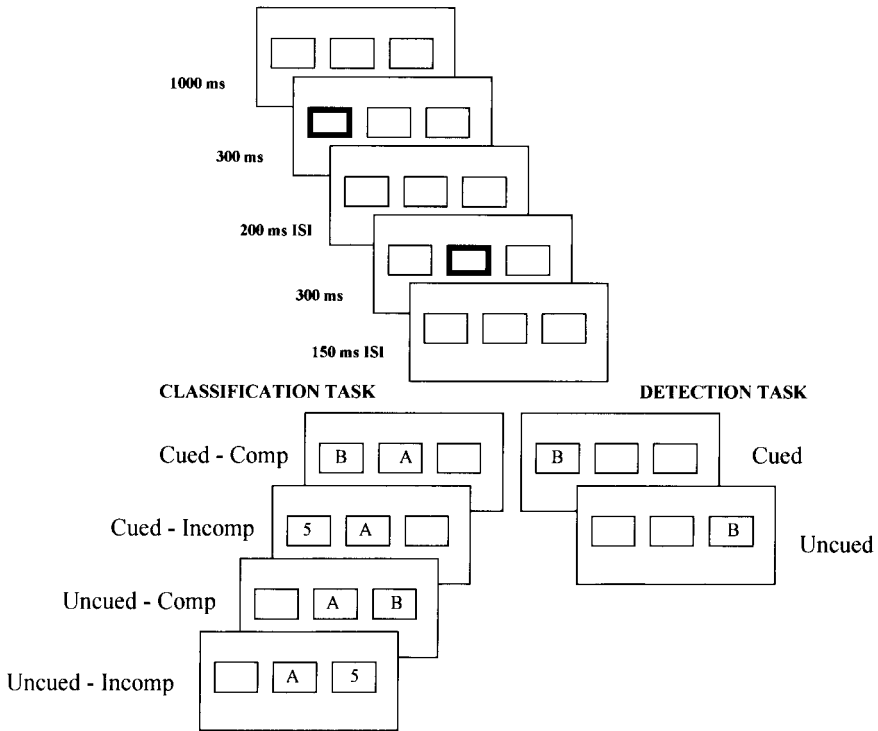


FIG. 2. Sequence of events and exposure durations of stimuli in Experiments 3 and 4.

one of the two peripheral locations. In the *classification* task (on 25% of the trials), participants responded to the category of a central letter or number (A or 4), which appeared simultaneously with the peripheral stimulus (now a distractor).² In the classification task, the distractor could be compatible or incompatible with the response to the central target. Prior to any letters or numbers occurring, participants were again cued to attend to one of the peripheral locations, and then attention was shifted back to the central location. Performance in the detection task provides a within-experiment measure of IOR (are detection responses slowed to stimuli at cued relative to uncued locations?). Performance in the classification task, on the other hand, indicates whether IOR to distractor locations influences response competition from incompatible distractors.

² We used a higher proportion of trials in the detection task than in the classification task to bias participants' attention to the cued location throughout the whole experiment. We assume that this could maintain the functional properties of the cue on the classification trials as well. The results of Experiments 3 and 4 support that assumption, because we observed a differential effect of distractors appearing at cued locations, compared to when they appeared at uncued locations.

Method

Participants

Twenty-two undergraduates from the Universidad de Almería participated. Participants received course credit for their participation. All had normal or corrected-to-normal vision.

Stimuli and Procedure

The letters A and B and digits 4 and 5 were used as target and distractor stimuli. Targets were always the letter A or digit 4, and distractors were always the letter B or digit 5. In the classification task there were four conditions: *cued-compatible* (distractor in cued location, target and distractor from the same category); *cued-incompatible* (distractor in cued location, target and distractor from different categories); *uncued-compatible* (distractor in uncued location, same category); and *uncued-incompatible* (distractor in uncued location, different category).

The letters and digits appeared within white boxes, which subtended $2.5^\circ \times 1.3^\circ$ at the viewing distance of 60 cm, and the inner sides of the peripheral boxes were located 2.6° from fixation. Peripheral stimuli were presented 3.8° from fixation, and they subtended $0.48^\circ \times 0.38^\circ$ in 40-column text mode. Participants received one block of 20 practice trials followed by an experimental block of 128 trials.

On each trial there was a central fixation cross (for 500 msec), followed by the three white boxes (for 1000 msec). One peripheral box then went red (for 300 msec), followed by an interval of 200 msec with white boxes. The central box then went red (the central cue) for 300 msec, followed by a further ISI of 150 msec before target displays appeared (i.e. cue–target SOA was 950 msec). The target and the distractor stimulus were presented until a response was made.

In the detection task participants pressed the space bar for detection responses using the left hand; in the classification task they pressed one key for letters and the other key for numbers.

The keys were K and L, respectively, for half of the participants, and the reverse for the other half. Participants made detection responses with a finger of their left hand, and classification responses with two fingers of the right hand. The two tasks were randomly intermingled, so that it was just the appearance of the display that indicated which task should be performed on each trial.

Results

The mean of the median correct RTs and the percentage of errors are presented in Table 2 (for the classification task only). In the *detection* task, RTs were longer when the target appeared at the cued location than when it appeared at the uncued location—489 msec versus 464 msec, $F(1, 21) = 13.7$, $p < .01$. This confirms that there was an IOR effect.

In the *classification* task, there was no overall effect of the cued location, but there was a reliable interaction between the cued location (cued vs. uncued) and the flanker condition (compatible vs. incompatible), $F(1, 21) = 12.5$, $p < .01$. The difference between classification times when distractors were compatible and when they were incompatible was reliable at both the cued and the uncued locations, $F(1, 21) = 7.0$ and 6.3 , respectively, both $p < .05$. Importantly, however, the compatibility effects went in *opposite* directions for flankers in the cued and uncued locations. At the uncued location the “standard” effect arose; RTs to compatible stimuli were faster than those to incompatible stimuli (by 48 msec). In contrast, at the cued location RTs to incompatible stimuli were faster than those to compatible stimuli (by 41 msec). There were no reliable effects in the error data.

TABLE 2
 Mean of Median Reaction Times and Percentage of Errors as a Function of Location
 and Condition

<i>Location</i>	<i>Experiment 3</i>				<i>Experiment 4</i>					
	<i>Compatible</i>		<i>Incompatible</i>		<i>Compatible</i>		<i>Neutral</i>		<i>Incompatible</i>	
	<i>Mean</i>	<i>Errors</i>	<i>Mean</i>	<i>Errors</i>	<i>Mean</i>	<i>Errors</i>	<i>Mean</i>	<i>Errors</i>	<i>Mean</i>	<i>Errors</i>
Cued	755	1.7	714	1.7	724	5.1	700	3.1	698	1.2
Uncued	710	3.4	759	2.3	690	3.3	706	3.7	719	2.3

Discussion

The difference between the response-compatible and incompatible conditions in the flanker task (with RTs slowed in the incompatible condition) is extremely reliable and has been observed on many occasions in many laboratories (see Eriksen, 1995). It is thus striking to find a reversal of the effect (with RTs slowed in the compatible condition). However, given that IOR reversed semantic priming at the short prime–target interval used here (see Experiment 2b), we had predicted that the standard compatibility effect in the current flanker task might also be reversed by IOR—exactly as we found to be the case.

To account for this result, we can propose a similar idea to that put forward to explain the negative effect of semantic priming in Experiment 2b. Essentially, IOR affects the links between the attributes of a stimulus appearing at an inhibited location and a response (i.e. the categorization response, in the present study). This inhibition of the link between a distractor’s category and the associated response slows performance when the target belongs to the same category as the distractor.

EXPERIMENT 4 IOR and the “Flanker” Task, a Replication

Experiment 3 showed an intriguing finding: Compatible distractors produced longer RTs than incompatible ones when presented at inhibited locations in a flanker paradigm. This was expected from results of Experiment 2b. But as, to our knowledge, no other study has reported such a reversal of the standard pattern in the flanker task, we sought to replicate the result in Experiment 4, with two modifications. First, a neutral condition was included for both the detection task and the classification task. This should have allowed us to determine whether any differences between performance with compatible and incompatible distractors in the IOR condition were due to inhibition of compatible distractors or facilitation of incompatible distractors. Second, two blocks of experimental trials were given to collect more data in each condition.

Method

The method was the same as in Experiment 3, except that a neutral condition was included. Stimuli for this condition were “¥” and “§”, which could appear as targets in the detection task and as distractors in the classification task. As in Experiment 3, both tasks were randomly intermingled, so that it was only the appearance of the display that indicated which task should be performed on each trial. Participants received one block of 32 practice trials followed by two experimental blocks of 192 trials. Thirty-two undergraduates from the Universidad de Almería participated. Participants received course credit for their participation, and all had normal or corrected-to-normal vision.

Results

The mean of the median correct RTs and the percentage of errors are presented in Table 2 (for the classification task only). In the detection task, data were submitted to an ANOVA with target type (neutral, digit-letter) and location (cued, uncued) as within-subject factors. As in Experiment 3, RTs were longer when the target appeared at the cued location than when it appeared at the uncued location—462 msec versus 451 msec), $F(1, 31) = 23.9$, $p < .001$, thus replicating the IOR effect. The main effect of target type and the Target Type \times Location interaction were not reliable, $F(1, 31) = 2.8$, $p > .10$; and $F < 1$, respectively.

In the *classification* task, the results replicated those in Experiment 3. There was no overall effect of either the cue location or the flanker condition (both F s < 1), but there was a reliable interaction, $F(2, 62) = 6.7$, $p < .01$. Analysis of the simple effects revealed an overall effect of the flanker condition at the cued location, $F(2, 62) = 3.5$, $p < .05$. Post-hoc comparisons showed reliable differences between the compatible condition and both the neutral and the incompatible conditions (both $p < .05$). There were no differences between the latter two conditions. There was also an overall effect of the flanker condition for the uncued location, $F(2, 64) = 3.2$, $p < .05$. Post-hoc analysis showed reliable differences between the compatible condition and the incompatible one ($p < .05$). No other comparisons reached reliable differences. The error analysis showed a main effect of the flanker condition, $F(2, 62) = 4.48$, $p < .05$. Post-hoc comparisons showed that there was a reliable difference between the compatible and the incompatible condition—4.2% vs. 2.1% ($p < .01$). No other effects were reliable.

Discussion

These results replicate those of Experiment 3, with opposite RT effects of flanker–target compatibility for flankers falling in the cued versus uncued locations. At the uncued location, the standard flanker effect was observed. At the cued location, however, RTs to incompatible distractors were faster than those to compatible ones. The inclusion of the neutral condition reduced the compatibility effect compared to Experiment 3 for both cued and uncued locations (see Table 2) but did not affect the unusual pattern of results observed at cued locations (i.e. the reversal of the standard flanker effect). Relative to the neutral condition, responses to compatible targets were slowed when distractors fell at the cued location, rather than responses to incompatible targets being speeded (note, however,

that a reliable difference between the neutral and incompatible condition was also absent for the uncued location, even though it is usually found with the standard procedure). This finding is consistent with there being temporary inhibition of the links to the responses for all attributes of stimuli falling at the cued (and previously attended) location. This slows RTs to targets when they belong to the same category as distractors at the cued location.

GENERAL DISCUSSION

We have presented four experiments in which we combined procedures that produce IOR with those thought to tap particular levels of information processing: activation of stored knowledge (semantic priming) and the activation of responses (flanker interference). In both paradigms we used presentation conditions that produced an IOR effect on target detection (Experiments 1a, 3, and 4), and in both paradigms (Experiments 2b, 3, and 4) we found that IOR could reverse the standard effects (which were observed when stimuli fell at uncued locations). In Experiments 1 and 2, prime words were presented at previously cued or uncued locations, followed by targets to which participants made lexical decisions. In Experiments 1a and 2a, the SOAs between primes and subsequent targets were relatively long (800 msec and 500 msec, respectively). IOR then had no effect on semantic priming. However, with a shorter SOA (250 msec), and a slightly shorter prime exposure (150 msec), IOR and semantic priming interacted. There was now a reversed effect of semantic priming when primes fell at cued locations, even though (standard) positive priming occurred when primes fell at uncued locations. We have suggested that there was a negative effect of semantic priming at the short SOA because inhibitory tags were temporarily applied to the representations of stimuli falling at previously attended locations. These tags effectively provide a temporary disconnection of activated representations from response processes, even when no overt response must be made to primes (as in the priming studies). If there is a spread of this tagging process to related as well as to prime representations, semantically related primes will slow RTs to targets. However, if the inhibitory tags decay relatively quickly, primes then facilitate target responses at longer prime–target intervals because the representations of targets were pre-activated.

In Experiments 3 and 4 we examined the effects of IOR on flanker interference, a measure of response competition between stimuli. When distractor stimuli appeared at uncued (non-inhibited) locations, the standard flanker effect was found: RTs were slower when targets and distractors were incompatible than when they were compatible. Exactly the opposite result occurred when distractors appeared at cued (inhibited) locations: RTs were faster in the incompatible than in the compatible condition. Experiment 4 included a neutral condition and suggested that the reversal of the compatibility effect was primarily due to RTs to compatible targets being slowed. The data support the idea that IOR prevents stimuli at inhibited locations from contacting associated responses. Categorical representations activated by distractors are given inhibitory links to categorization responses. As a consequence, responses to targets belonging to the same category (i.e. the compatible condition) are slowed.

The mechanism of inhibitory tagging can provide a general account of IOR in a variety of paradigms. For instance, tasks involving the detection of peripheral targets may be mediated by the programming of eye movements to the targets. IOR can then involve

inhibitory tagging of information from previously attended locations for the eye movement system (cf. Rafal et al., 1989). However, as we noted in the introduction, IOR has been shown *not* to occur in tasks requiring temporal order judgements or judgements of motion perception (Maylor, 1985; Schmidt, 1996), and several failures to observe IOR have been reported when two-choice rather than simple discrimination responses are required to targets (Klein & Taylor, 1994). Yet, we have found consequences of IOR on the effects of prime and distractor stimuli on two-choice responses to targets. Thus, how do the present results fit with the lack of IOR effects in discrimination tasks? In other words, how is it possible to find IOR effects on performance with a type of task that others have found insensitive to IOR?

A possible account for the lack of IOR in discrimination tasks can be found in the study by Lupiáñez et al. (1997). They measured the time course of IOR both in a detection task and in a discrimination task similar to that used by Terry, Valdes, & Neill (1994). In the detection task IOR appeared after a 400-msec cue–target delay and was still present after 1300 msec. In the discrimination task the effect appeared after a delay of 700 msec and showed a tendency to disappear over time. In recent studies, we have consistently observed IOR in tasks such as lexical decisions (Fuentes, et al., 1998), or target categorization (Fuentes, Langley, Overmier, Bastin de Jong, & Prod’Homme, 1998). In all cases, as in the present study, the cue–target SOA that we used was within the values Lupiáñez and co-workers found to be crucial to observe IOR.

However, one other potentially crucial difference between the present procedure and previous investigations using two-choice discriminations is that, in the crucial conditions, we did not require observers to respond directly to the item that was subject to IOR but, rather, had them respond to a spatially separated target (e.g. classification task in Experiments 3 and 4). Thus, in our experiments, participants needed to keep activation from prime and distractor stimuli separate from that generated by targets, so that responses were based on target information. One way of keeping activation separate is to bind activation from primes to a spatial location, which, in our procedure, is also subject to IOR. The novel result we have shown is that, following this, there is inhibitory tagging of semantic and categorical properties of the stimulus for decision making. Thus, we suggest that IOR does not simply involve the inhibition of saccadic responses within a visual–perceptual action system but can involve inhibition of the links from the semantic properties of stimuli to response systems when those properties are bound to location information. We found that these effects are revealed when multiple stimuli are presented (i.e. target plus distractor), which must be kept separate for response purposes.

REFERENCES

- Broadbent, D.E. (1971). *Decision and stress*. London: Academic Press.
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*, 193–222.
- Eriksen, C.W. (1995). The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition, 2*, 101–118.
- Eriksen, B.A., & Eriksen, C.W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*, 143–149.
- Fuentes, L.J., Langley, L.K., Overmier, J.B., Bastin de Jong, C., & Prod’Homme, M.M.

- (1998). Attention-dependent semantic priming and inhibition of return in older adults and adults with Alzheimer's disease. Poster presented at the Cognitive Aging Conference, Atlanta.
- Fuentes, L.J., Vivas, A.B., & Humphreys, G.W. (in press). Inhibitory mechanisms of attentional networks: Spatial and semantic inhibitory processing. *Journal of Experimental Psychology: Human Perception and Performance*.
- Gibson, B.S., & Egeth, H. (1994). Inhibition and disinhibition of return: Evidence from temporal order judgements. *Perception & Psychophysics*, *56*, 669–680.
- Houghton, G., Tipper, S.P., Weaver, B., & Shore, D.I. (1996). Inhibition and interference in selective attention: Some tests of a neural network model. *Visual Cognition*, *3*, 119–164.
- Klein, R.M., & Taylor, T.L. (1994). Categories of cognitive inhibition with reference to attention. In D. Dagenbach & T.H. Carr (Eds.), *Inhibitory mechanisms in attention memory and language* (pp. 113–150). San Diego: Academic Press.
- Lupiañez, J., Milán, E.G., Tornay, F.J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks?: Yes, it does, but later. *Perception & Psychophysics*, *59*, 1241–1253.
- Maylor, E.A. (1985). Facilitory and inhibitory components of orienting in visual space. In M.I. Posner & O.S.M. Marin (Eds.), *Attention and performance XI*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Meyer, D.E., & Schvaneveldt, R.W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, *90*, 227–234.
- Müller, H.J., & Humphreys, G.W. (1991). Luminance-increment detection: capacity-limited or not? *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 1, 107–124.
- Neely, J.H. (1977). Semantic priming and retrieval from lexical memory. *Journal of Experimental Psychology: General*, *106*, 226–254.
- Neely, J.H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Posner, M.I. (1978). *Chronometric explorations of mind*. New York: Oxford University Press.
- Posner, M.I., & Cohen, Y.A. (1984). Components of visual orienting. In H. Bouma and D.G. Bouwhuis (Eds.), *Attention and performance X* (pp. 513–556). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42.
- Posner, M.I., Rafal, R.D., Choate, L.S., & Vaughan (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology*, *2*, 211–228.
- Pratt, J. (1995). Inhibition of return in a discrimination task. *Psychonomic Bulletin & Review*, *2*, 117–120.
- Pratt, J., Kingstone, A., & Khoe, W. (1997). Inhibition of return in location- and identity-based choice decision tasks. *Perception & Psychophysics*, *59*, 964–971.
- Rafal, R.D., Calabresi, C.W., Brennan, C.W., & Sciolto, T.K. (1989). Saccade preparation inhibits reorienting to recently attended locations. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 673–685.
- Reuter-Lorenz, P.A., Jha, A.P., & Rosenquist, J.N. (1996). What is inhibited in inhibition of return? *Journal of Experimental Psychology: Human Perception & Performance*, *22*, 367–378.
- Schmidt, W.C. (1996). Inhibition of return is not detected using illusory line motion. *Perception & Psychophysics*, *58*, 883–898.
- Schneider, W.X. (1995). VAM: A neuro-cognitive model for visual attention control of segmentation, object recognition and space-based motor action. *Visual Cognition*, *2*, 331–376.
- Terry, K.M., Valdes, L.A., & Neill, W.T. (1994). Does “inhibition of return” occur in discrimination tasks? *Perception & Psychophysics*, *55*, 279–286.
- Tipper, S.P., Weaver, B., Jerreat, L.M., & Burak, A.L. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 478–499.
- Watson, D.G., & Humphreys, G.W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review*, *104*, 90–122.