Journal of Experimental Psychology:
Human Perception and Performance
2006, Vol. 32, No. 4, 908–919

0096-1523/06/$12.00 DOI: 10.1037/0096-1523.32.4.908

Inhibition of Return: Sensitivity and Criterion as a Function of Response Time

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Inhibition of return (IOR) refers to a mechanism that results in a performance disadvantage typically observed when targets are presented at a location once occupied by a cue. Although the time course of the phenomenon—from the cue to the target—has been well studied, the time course of the effect—from target to response— is unknown. In 2 experiments, the effect of IOR upon sensitivity and response criterion under different levels of speed stress was examined. In go/no-go and choice reaction time tasks, IOR had at least 2 distinct effects on information processing. Early in target processing, before sufficient target information has accrued, there is a bias against responding to cued targets. Later, as target information is allowed to accrue, IOR reduces sensitivity to the target's nonspatial feature. Three accounts relating to the early bias effect of IOR and the late effect of IOR on sensitivity are offered.

Keywords: inhibition of return, attention, orienting, speed-accuracy tradeoff, information processing dynamics

Searching for an item among an array of distractors can be time consuming especially when there are many distractors that are not readily distinguishable from the target. In this scenario, it is generally presumed that attention is deployed from item to item until the target is eventually processed (i.e., in a serial, self-terminating fashion). A current debate concerns whether search is anarchic and amnesic (e.g., Horowitz & Wolfe, 1998; but see Gibson, Li, Skow, Brown, & Cooke, 2000; Kristjánsson, 2000; Peterson, Kramer, Wang, Irwin, & McCarley, 2001; von Mülenen, Müller, & Müller, 2003) or whether orienting toward previously sampled items is discouraged by inhibitory tags (Klein, 1988). Indeed, Klein and others (Müller & von Muhlenen, 2000; Samuel & Weiner, 2001; Takeda & Yagi, 2000) have observed slower detection responses to probe stimuli presented at locations occupied at distractor locations rather than at previously unoccupied locations, suggesting that inhibitory tagging facilitates orienting to new locations in visually cluttered environments.

The impetus for Klein's (1988) study of potentially inhibitory processes in search came from a peripheral cuing study by Posner and Cohen (1984; see also Posner, Rafal, Choate, & Vaughan, 1985). Posner and Cohen discovered that peripheral cues, which do not predict the forthcoming location of a target, had two effects on response times (RTs) to targets. These effects were dissociable by manipulating the cue to target interval (i.e., cue–target onset asynchrony [CTOA]). First, when CTOAs were less than about 300 ms, RTs were faster when the cue and target appeared at the same location than when they appeared in different locations. This effect is believed to be the result of attention shifting to the cue and facilitating the detection and subsequent processing of the target. The second effect showed up approximately 300 ms following the cue's onset. With CTOAs greater than 300 ms, Posner and Cohen observed that RTs were slowed when the cue and target appeared at the same location. This effect, coined *inhibition of return* (IOR) by Posner et al., was thought to be the result of a hypothetical mechanism inhibiting attention from returning to a location from whence it had been recently withdrawn. According to Posner and Cohen, the function of this effect is to promote orienting to new locations by discouraging attention from resampling previously visited locations.

Despite hundreds of research papers on IOR since Posner and Cohen's (1984) discovery of the phenomenon, little is known about the mechanism by which IOR operates. In cuing tasks, the effect of IOR on delaying RTs is well documented. While a mechanism that inhibits attention is expected to delay RTs, delayed RTs are not conclusive proof of inhibited attention. For instance, the *criterion-shift account* of the IOR effect (Ivanoff & Klein, 2001, 2004; Klein & Taylor, 1994) argues that the mechanism responsible for IOR acts to bias against responding to targets at the cued location. In other words, the IOR effect is the result of a pigeonholing mechanism (cf. Broadbent, 1971) such that more target evidence is required when responding to cued targets than to uncued targets. Accordingly, by raising the criterion for responding to cued targets, not only are RTs slowed but accuracy ought to be improved when responding to cued targets so long as the target is neither brief nor masked. However, the *inhibited attention* theory of IOR presumes that the negative effect of IOR is directly opposite that of the positive effect of attention. Thus, whereas attention is presumed to improve the gain of information accrual (e.g., Carrasco & McElree, 2001), IOR ought to reduce it. The

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This work was supported by a grant from the McDonnell-Pew Foundation and a Natural Sciences and Engineering Research Council of Canada-Postgraduate Scholarship. We thank Howard Egeth, Jan Theeuwes, and Marisa Carrasco for helpful comments on previous versions of this article.

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inhibited attention theory predicts that RTs will be slowed and accuracy will be reduced for cued targets. Thus, while the theories make similar predictions concerning the effect of IOR on RTs, they make very different predictions concerning the effect upon accuracy rates.

Evidence for Inhibited Attention

Numerous investigations have claimed to find evidence for the inhibited attention account of IOR. Some have attempted to observe effects of IOR on performance that are counter to the effects of attention on performance (e.g., Reuter-Lorenz, Jha, & Rosenquist, 1996). Whereas these studies have typically concentrated on RTs rather than response accuracy, the inhibited attention view, however, requires joint consideration of these two dependent variables. Detection tasks are not well suited for measuring the effects of IOR on accuracy, as it is impossible to attribute false alarms to cued and uncued conditions. The effects of IOR on RT in these tasks may be attributed to inhibited attention or criterion-shift effects. Experiments that have used go/no-go targets (i.e., a *c*-reaction, according to Donders's 1969 taxonomy) have demonstrated reduced (Handy, Jha, & Mangun, 1999; Lupiáñez & Milliken, 1999) and enhanced (Ivanoff & Klein, 2001, 2003; Taylor & Ivanoff, 2003) accuracy. In choice RT tasks, the evidence for reduced accuracy is also mixed. Figure 1 portrays the relation between RT and accuracy measures of IOR (i.e., the cued–uncued difference) in several choice RT studies using a standard cuing paradigm wherein the target attribute to be discriminated was not spatial. As shown in Figure 1, despite the variability, the overall pattern is consistent with the inhibited attention account. Thus, on average, it seems that IOR slows RTs and reduces accuracy. However, only one of these studies (Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997, Experiments 4b and 5b) reported a significant effect of IOR on accuracy.

A methodological aspect of every study to date that has found a negative effect of IOR on accuracy makes interpretation of this negative effect ambiguous. Specifically, removing the target shortly after its onset (Lupiáñez et al., 1997), or masking the target shortly after its presentation (Cheal & Chastain, 1999; Cheal, Chastain, & Lyon, 1998; Handy et al., 1999; see also Klein & Dick, 2002), will truncate the natural accrual of information (see

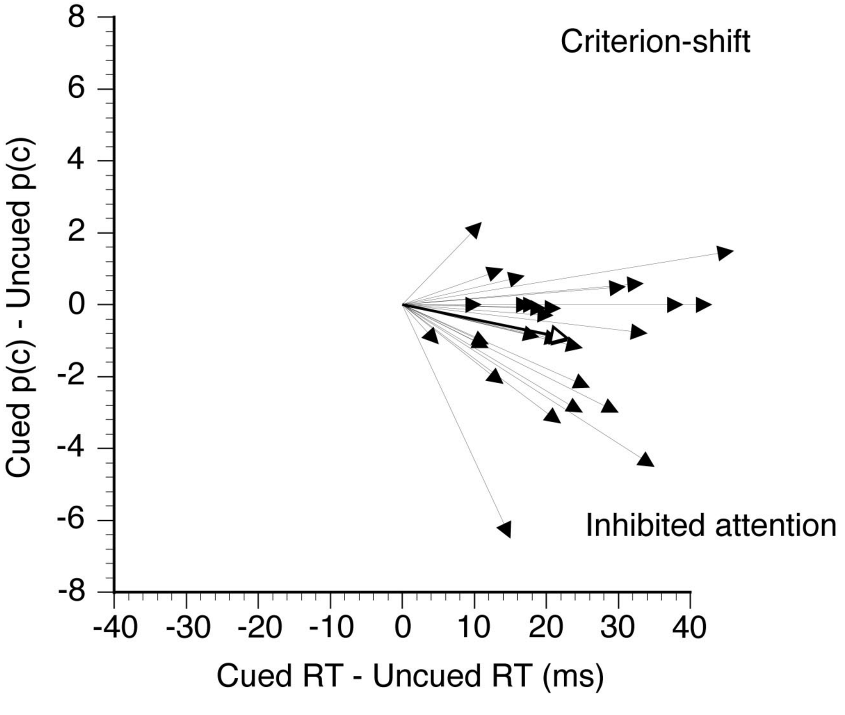

Figure 1. The results from a sample of investigations of inhibition of return (IOR) in choice reaction time (RT) tasks based on a nonspatial discrimination of the target. Vectors with filled arrowheads reflect individual experiments (see text for list), and the vector with the unfilled arrowhead is the mean. Critically, those arrows that point downward (reflecting slowed RTs and poorer accuracy for cued than for uncued trials) are consistent with an inhibited attention account of IOR. Those arrows that point upward (reflecting slowed RTs and better accuracy for cued than for uncued trials) are consistent with a criterion-shift account of IOR. The following is the list of experiments that contributed to this figure: Gibson & Amelio, 2000; Kingstone & Pratt, 1999, Experiments 1 and 2; Lupiáñez et al., 1997, Experiments 2b, 3b, 4b, and 5b; Lupiáñez & Milliken, 1999, Experiments 2a and 2b; Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001, Experiments 1b; Pratt, Kingstone, & Khoe, 1997, Experiments 1, 2, and 3; Pratt & McAuliffe, 2002, Experiment 2; and Taylor & Donnelly, 2002, Experiments 2 and 4. In these studies, there is one target and one cue, and responses were not made to the cue. Only those experimental conditions that demonstrated slower responses to cued than to uncued trials (i.e., an IOR effect) were included.

Ivanoff & Klein, 2001, 2004; Taylor & Klein, 1998). Under these conditions, responding may be based on decaying information rather than on accumulating information (Klein & Kerr, 1974; Posner, 1975), and consequently any factor that causes a delay in responding (viz., IOR) may incidentally impair accuracy (see Lachter & Durgin, 1999, for evidence that slowed responding results in lower accuracy under conditions of maximal masking). This construal of IOR's effect on response accuracy under conditions of data-limited targets is illustrated, along with the results from Handy et al. (1999), in Figure 2. Note that in Handy et al.'s second experiment, participants were given the opportunity to respond more slowly than they did in Experiment 1. The *d′* was substantially reduced in this second experiment, as predicted by the suggestion that with data-limited stimuli, accuracy declines because of a decay process. Unfortunately, the literature to date does not paint a complete picture of IOR's effect on accuracy under conditions in which target information is accruing.

Evidence for a Criterion Shift

The criterion-shift account of IOR is a type of motoric explanation for the RT effect. To date, we believe that there are just two, relatively convincing, findings that are consistent with an effect of IOR on the response criterion. First, Ivanoff and Klein (2001) observed slower RTs, and yet fewer false alarms (i.e., responses to no-go targets in a go/no-go task), to cued targets than to uncued targets. This finding was observed under conditions in which the target remained visible until the response was made. Since this report, this finding has been replicated in different experimental contexts (e.g., Ivanoff & Klein, 2003; Taylor & Ivanoff, 2003). Recently, we (Ivanoff & Klein, 2004) observed that the effect of IOR on reducing false alarms (and errors in a choice RT task) is contingent on the use of asymmetric stimulus–response (S-R) probabilities (i.e., one S-R ensemble occurs more frequently than the other ensemble). Specifically, when one target was more frequent than another, the effect of IOR on error rate was largest for the infrequent target. Error rates were low, and little affected by IOR, when the target was frequent. Thus, IOR seemed to reduce errors (to infrequent targets) by mediating the miscategorization of infrequent events as frequent ones (i.e., making the frequent response to the infrequent target; see also Klein & Hansen, 1990, who observed a similar interaction but with endogenous attention rather than IOR). In other words, it was as though likely targets were expected to appear at the uncued location. This finding would be expected given that IOR acted at decision-level stages of information processing, but it does not argue against the idea that IOR is related to effects upon attention.

Goals of the Current Experiments

In contrast to previous studies that have measured the effects of IOR on accuracy, potentially, under conditions of decaying target information (Cheal & Chastain, 1999; Cheal et al., 1998; Handy et al., 1999; Klein & Dick, 2002), the current experiments were designed to measure accuracy under different levels of speed stress while target information is accumulating. Under such conditions, however, it will be necessary to measure accuracy before the quality of target information reaches asymptote (i.e., before accu-

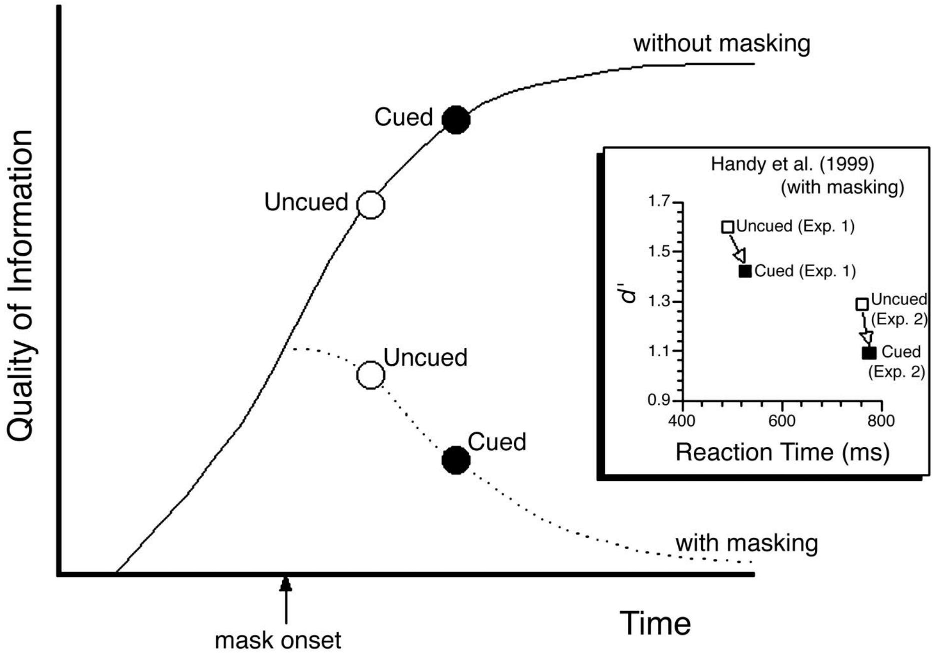

Figure 2. A depiction of the possible effect of inhibition of return (IOR) under conditions with (regular line and dashed line) and without target masking. In the case of target masking, the onset of the mask is indicated along the time axis. The inset figure illustrates the results from Handy et al. (1999). With masking, it is possible that slower reaction times result in reduced *d′* simply because information is decaying. The figure is based on Posner (1975) and Klein and Kerr (1974).

racy reaches ceiling levels of performance) so as to avoid potentially deflated or null effects of IOR on accuracy. To accomplish this goal, we used a response signal technique, as is often used to measure the speed–accuracy trade-off (SAT) function (e.g., Pachella, 1974; Reed, 1973; Wickelgren, 1977) to constrain responding within certain temporal windows following the onset of the target. Following the target's onset, a tone signaled the onset of the response window. Participants used the tone to pace their responses. By manipulating the target–tone onset asynchrony (TTOA), we can induce fast and slow responses and measure accuracy as a function of RT. Prior SAT research on visual attention in a cuing paradigm revealed more accurate responses to cued than to uncued targets when RT was controlled (Carrasco & McElree, 2001; McCormick & Francis, in press). Accordingly, if IOR serves to inhibit reorienting of attention, we expect IOR to decrease sensitivity when RT to unmasked targets is controlled.

Alternatively, if IOR manifests only as a criterion shift, we would expect different effects upon information processing. First of all, IOR ought to increase *c*, the criterion metric of signal detection theory. Positive values of *c* indicate conservative responding, and negative values indicate a liberal responding policy. Second, the effect of IOR on accuracy ought to be conditional on finding an effect of IOR on RT within the window. If RT is adequately controlled, such that RTs within the response windows are comparable for cued and uncued trials, then there ought not to be any effect of IOR upon sensitivity (d'). Alternatively, if cued RTs are slower than uncued RTs (despite the intention to constrain them within the response window), then we ought to see higher sensitivity values for cued targets than for uncued targets (unless accuracy is at asymptote, in which case there ought not to be any difference between accuracy on cued and uncued trials). Thus, examining the effect of IOR at multiple points in time following target presentation ought to permit a direct assessment of these competing (though not necessarily mutually exclusive) hypotheses.

Experiment 1

The goal of this experiment is to assess the effects of IOR on d' and *c* in a go/no-go task under different levels of speed stress using the response signal technique frequently used in SAT analyses. Unlike in Ivanoff and Klein (2001), wherein go targets were much more likely than no-go targets, in the present study the two targets were equally likely. The target's nonspatial feature (⊗ vs. ⊕) was used to signal whether a single response should be withheld (a no-go target: ⊗) or executed (a go target: ⊕). Following the onset of the (go or no-go) target, a tone sounded indicating that responses ought to be made immediately. Feedback was given at the end of every go trial to inform participants whether the response was made within the response window. Hits (responses to go targets within the window) and false alarms (responses to no-go targets within the window) were used to derive measures of sensitivity d' and the criterion (*c*) in signal detection theory. An effect of cuing on d' suggests that the observer's sensitivity to target's identity is affected by IOR. An effect of cuing on *c* suggests that the cue has altered the decision criterion. Note that the criterion-shift account of IOR is not only about criterion (*c*) changes in signal detection theory, but also concerns the trade-off between sensitivity (d') and response time.

Method

Participants. Ten students from Dalhousie University participated in the study for course credit.

Apparatus, stimuli, and procedure. The experiment was conducted on a 630 Mac, and participants were seated approximately 57 cm from the computer monitor. The trial sequence is depicted in Figure 3. Every trial began with a blank 450-ms intertrial interval (not shown in Figure 3). Following this, three horizontally aligned squares were presented with the fixation point in the middle square. Each side of the square was 1.3° (visual angle). The distance between the square placeholders was 6.2°. The fixation point was a hollow circle: 0.9° in diameter and 0.2° thick within the central square placeholder. This fixation display remained on throughout the trial, but was removed during the blank intertrial interval. After the onset of the fixation display, the cue appeared in the left or right square for 90 ms. The cue was a gray square, the same size as the existing square placeholder. After the cue was removed, the fixation point and the three squares were presented alone for 60 ms. The central fixation point enlarged

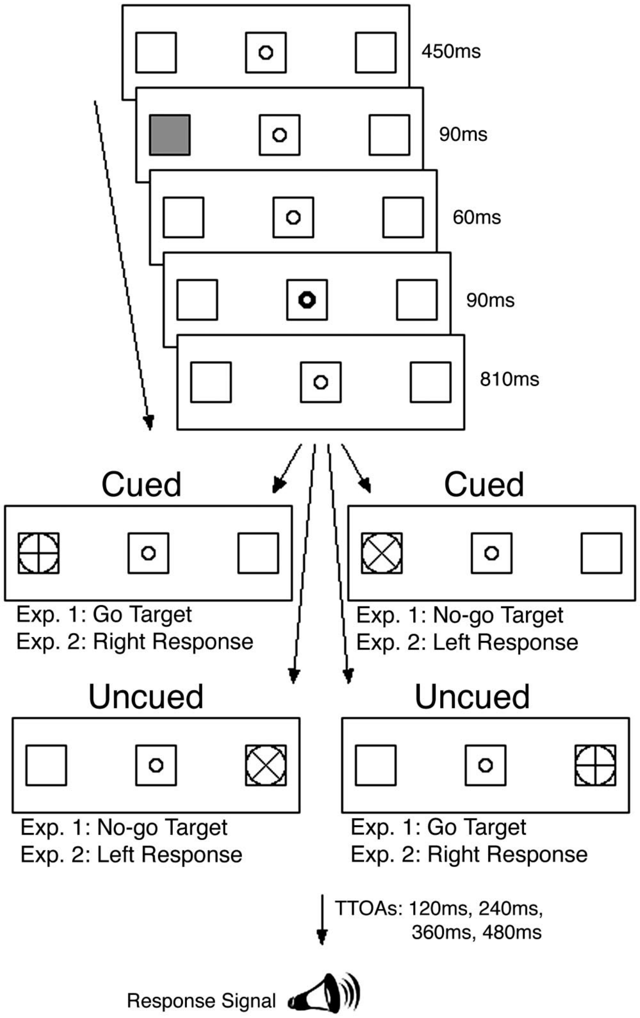

Figure 3. The trial events of Experiments 1 and 2 (not to scale). In Experiment 1, a response is made to the go target and withheld when the no-go target is presented. In Experiment 2, a left response is made to the *X* and a right response is made to the +. In both experiments, a response signal (tone) follows the target instructing participants to respond immediately. TTOA = target–tone onset asynchrony.

(to 1.1° in diameter and 0.6° thick) for 90 ms. The fixation point and square placeholders were then presented alone for 810 ms. Finally, the target appeared in the left or right square. As always, the cue's location did not predict the target's location (i.e., the cue and targets were shown at the same location only 50% of the time). The target was a ⊕ or ⊗ with each line, however, extending to the circle surrounding it. The ⊕ symbol was 1.3° wide and 1.3° tall. The ⊗ was the same size as the ⊕, but rotated 45°. The ⊕ and ⊗ targets were presented, with equal frequency, until a response was made or until the end of the response window. As shown in Figure 3, there were four types of trials, each equiprobable.

One of four TTOAs (120 ms, 240 ms, 360 ms, and 480 ms)[1] was presented in separate blocks. The order of TTOAs was ascending or descending, counterbalanced between participants. The tone signaled a 210-ms response window in which participants were instructed to make the appropriate response. Participants were instructed to make a keypress with the index finger of the right hand on the *N* key whenever the ⊕ was presented and to withhold responding whenever the ⊗ was presented. The cuing condition referred to whether the cue and target appeared in the same location (cued targets) or in different locations (uncued targets).

There were six blocks of trials, taking nearly 2 hr to complete. The blocks were completed in two 1-hr sessions within the same week. The first and last (sixth) blocks comprised 40 trials for which participants were instructed to respond quickly and accurately. The response signal was not used. The purpose of these blocks was to assess performance before and after the response signal task.[2] The middle blocks were the blocks with the response signals. Each response signal block had 400 trials comprising 200 cued and 200 uncued trials.

Results

The data from each measure were entered into separate 4 (TTOA: 120 ms, 240 ms, 360 ms, and 480 ms) × 2 (cuing) repeated-measures analyses of variance (ANOVAs).

Tone–response time. The mean tone RTs, for responses to go targets, versus TTOA as a function of cuing are presented in Table 1. The main effects of TTOA, $F(3, 27) = 34.70$, $p < .001$, and cuing, $F(1, 9) = 6.94$, $p < .05$, were significant. The TTOA main effect indicated that tone RT decreased from the 120-ms TTOA to the 360-ms TTOA, with a slight (15 ms) upturn from the 360-ms to 480-ms TTOA. More important, there was a small, yet significant, 5-ms IOR effect overall. This pattern was observed in 8 of the 10 participants. The other 2 participants had 1-ms and 3-ms facilitation effects (i.e., cued RTs were faster than uncued RTs) overall. This suggests that even while our tone-marked window was intended to control RT, IOR nevertheless caused slower RTs within the windows. Although the interaction between cuing and TTOA was not significant, we call attention to the absence of a cuing effect in RT in the 480-ms TTOA because the same pattern was observed in Experiment 2.

Table 1
Mean Tone RTs (in Milliseconds), Anticipations, Hits, and False-Alcom Rates in Experiment 1

	Target-tone onset asynchrony (ms)			
Measure	120	240	360	480
Tone-RTs (ms) for go targets				
Cued	173	141	93	107
Uncued	169	132	90	106
Anticipations (%)				
Cued	1.5	1.8	63	15.0
Uncued	1.3	2.3	9.5	19.7
Hits (%)				
Cued	34.4	77.0	90.0	86.6
Uncued	43.9	79.7	91.6	85.8
False alarms (%)				
Cued	23.8	22.8	6.7	0.7
Uncued	30.1	19.4	3.8	0.4

Note. RTs = reaction times.

Anticipations. Anticipations are responses that occur after the onset of the target and before the response window, and likely reflect a general state of response readiness while awaiting a response signal. Table 1 provides the percentage of anticipations as a function of cuing and TTOA. The main effects of TTOA, $F(3, 27) = 29.07$, $p < .001$, and cuing, $F(1, 9) = 6.27$, $p < .05$, were significant. The percentage of anticipations increased with TTOA. Pairwise comparisons between each level of TTOA indicated that all differences were significant except the difference between the 120-ms and 240-ms TTOA. The main effect of cuing was the result of 2.05% more anticipatory responses to uncued targets than to cued targets.

Hits. A hit is a response that occurred within the response window. The percentage of hits was calculated without considering anticipations; that is, hits/(hits + misses) × 100. The mean hit values are provided in Table 1. The main effect of TTOA was significant, $F(3, 27) = 75.59$, $p < .001$. Generally, the percentage of hits increased as TTOA increased, with the exception that there was a significant drop from the 360-ms to the 480-ms TTOA. The main effect of cuing, $F(1, 9) = 10.72$, $p < .01$, and the interaction between TTOA and cuing, $F(3, 27) = 6.88$, $p < .005$, were

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[1] Our methodological approach to the speed–accuracy analysis of IOR is not the typical psychophysical approach to the SAT, wherein many TTOAs are collected over several days with a small sample of participants. The goal of such an approach is to fit a function to the results to extract features such as slopes, intercepts, and asymptotes (Wickelgren, 1977). Concerned that we may actually fail to observe IOR if too many trials are presented over an extended period of time (Weaver, Lupiáñez, & Watson, 1998; but see Pratt & McAuliffe, 1999), we opted to use a larger sample of participants and fewer TTOAs than the typical SAT procedure. Confirming our concern, when we attempted to use a larger sampling of TTOAs, we did not find strong evidence of IOR.

[2] The mean RTs and false-alarm rates from the first and last blocks were entered into a 2 (block: first and last) × 2 (cuing: cued and uncued) ANOVA. No effects were significant in the analysis of false alarms. However, there were 5.00% more false alarms in the last block than there were in the first block, and there were 1.50% and 0.50% more false alarms for uncued targets than for cued targets in the first block and last block, respectively. Only the main effect of block was significant in the analysis of RTs, $F(1, 9) = 44.40$, $p < .001$, indicating that responses were 106 ms slower in the first block than they were in the last block. The interaction between block and cuing approached significance, $F(1, 9) = 4.64$, $p = .06$. In the first block, responses to cued targets were 23 ms slower than responses to uncued targets, $t(9) = 2.20$, $p < .05$. However, in the last block, responses to cued targets were 3 ms faster than responses to uncued targets, but this effect in the last session was not significant. The reason that RTs were no longer slowed at the cued location is unclear. IOR may have been eliminated because of practice or fatigue. Alternatively, the release from the constraint of responding within the response window could have created a processing dynamic unlike that typically observed under "fast and accurate" instructions.

significant. An analysis of cuing effects at each TTOA revealed a significant difference at the 120-ms TTOA: There were 9.50% more hits for uncued targets than for cued targets, $t(9) = 4.62$, $p < .005$.

False alarms. A false alarm, in the context of the current experiment, is a response to a no-go target within the response window. The mean false-alarm rate versus TTOA, as a function of cuing, is presented in Table 1. The main effect of TTOA, $F(3, 27) = 22.31$, $p < .001$, and the interaction between TTOA and cuing, $F(3, 27) = 6.27$, $p < .005$, were significant. Pairwise comparisons between each level of TTOA indicated that false alarms decreased as TTOA increased and that the only nonsignificant comparison was between the 120-ms and 240-ms TTOAs. An examination of the cuing effects at each level of TTOA indicated that there were 6.40% more false alarms to no-go targets at the uncued location than at the cued location for the 120-ms TTOA, $t(9) = 2.90$, $p < .05$. In addition, there were 2.90% more false alarms for no-go targets at the cued location than at the uncued location at the 360-ms TTOA, $t(9) = 2.80$, $p < .05$. The false-alarm rate differences at the other TTOAs were nonsignificant.

Criterion (c). In the calculation of c and d', here and in the next experiment, extreme values of hits (1.0), and false alarms (0.0) were adjusted by removing or adding a trial from the total frequency (0.99 and 0.01, respectively). Positive criterion (c) values reflect conservative responding while negative values generally reflect a liberal response bias (see Macmillan & Creelman, 1991, p. 33). Anticipatory responses were excluded in the calculation of c values (and d' values, see below). Criterion values are presented in the inset in Figure 4. The main effects of TTOA, $F(3, 27) = 11.36$, $p < .001$, and the interaction between TTOA and cuing, $F(3, 27) = 5.42$, $p < .005$, were significant. Visual inspection of the data suggests that the interaction might be attributable to the large effect of cuing ($M = 0.61$ for cued and $M = 0.36$ for uncued) at the shortest TTOA, $t(9) = 3.34$, $p < .01$. This was confirmed by finding no interaction ($F < 1$) when the ANOVA was repeated excluding the 120-ms TTOA.

Sensitivity (d′). Figure 4 illustrates d' versus processing lag (TTOA plus tone RTs for go and no-go targets) as a function of cuing. Only the main effects of TTOA, $F(3, 27) = 130.62$, $p < .001$, and cuing, $F(1, 9) = 5.45$, $p < .05$, were significant, indicating that d' values increased as TTOA increased and that d' was lower on cued trials than on uncued trials (overall by 0.19). This negative effect of IOR on d' was observed in 8 of our 10 participants. The interaction between cuing and TTOA, $F(3, 27) = 1.73$, $p = .18$, was not significant.

Discussion

Despite the use of temporal windows to constrain RTs, IOR had a significant (5 ms) effect on tone RTs. While this might seem like a small effect, that it occurred under conditions of constrained responding (i.e., within a 210-ms window) is a testament to the potency of IOR in our task. More important than the effect of IOR on tone RT, for our purposes, is the effect of IOR on sensitivity (d'). If the IOR effect were nothing more than a criterion shift, then associated with this delay there should be a corresponding increase in sensitivity. The results suggest quite the opposite pattern, however, with significantly reduced sensitivity on cued trials. This finding extends previous

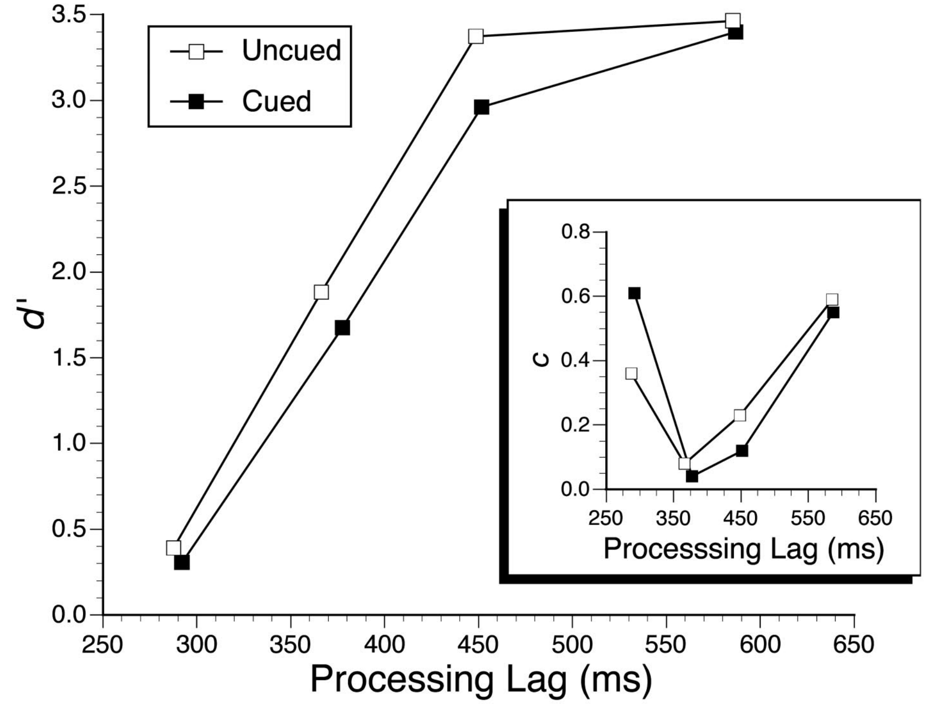

Figure 4. Sensitivity (d') versus processing lag (target–tone onset asynchrony plus tone reaction times for hits and false alarms) as a function of cuing (cued and uncued targets) in Experiment 1. The inset figure plots criterion (c) values versus processing lag as a function of cuing.

results by Handy, Cheal, and others (Cheal & Chastain, 1999; Cheal et al., 1998; Handy et al., 1999; Klein & Dick, 2002) who reported a similar finding using data-limited targets. The current experiment, however, provides the first evidence that IOR reduces the sensitivity to the target under conditions in which the target is not masked, briefly displayed, or rapidly replaced with another stimulus. On this basis, we suggest that IOR cannot be explained solely by a shift in the decision criterion and therefore lends some credence to the view that IOR has a negative effect on perception, attention, or both. Nonetheless, while the results support the inhibited attention theory of IOR, there are two findings suggesting that inhibited attention may not be the whole story.

The first finding that appears to support the criterion-shift account of IOR was observed within the analysis of c, the criterion. At the early (120-ms) TTOA, criterion values were higher for cued trials than for uncued trials.[3] The implication of this finding is that responding to cued targets is more conservative than responding to uncued targets. It is also important to bear in mind that, at the 120-ms TTOA, sensitivity to cued and uncued targets is essentially at chance levels (i.e., $d' \approx 0$). Thus, with no target information available, decisions to respond are less risky for targets affected by IOR. This is the kind of situation encountered in many serial search tasks in which attention has yet to disengage from an inspected location and is about to be launched to a new one. In the context of a cuing task, attention is pulled to the cue but is then subsequently removed. Hence, IOR may reflect an unintentional mechanism that biases responding to new places. It is unintentional as there is some evidence that IOR occurs irrespective of one's awareness of the cue (Ivanoff & Klein, 2003).

The second finding provides provisional evidence supporting the criterion-shift account of IOR. At the 480-ms TTOA, there were more anticipatory responses for uncued targets than for cued targets. If this type of anticipatory responding simply reflects the degree to which there is a readiness to respond, then this finding is consistent with the suggestion that IOR can be manifested as a bias to respond away from the cue. However, the effect of IOR on anticipations, by itself, is not definitive evidence against the inhibited attention account as hindering attention to cued targets may also lessen the probability of making an early (anticipatory) response.

Experiment 2

Determining whether IOR improves accuracy in a choice RT task is important because, as discussed in the introduction, those who have found evidence of reduced accuracy on cued trials compared with uncued trials have generally used choice RT tasks (as shown in Figure 1). As was pointed out earlier, those studies that have found lower accuracy on cued trials have also used data-limited targets (Cheal & Chastain, 1999; Klein & Dick, 2002; Lupiàñez et al., 1997), making the interpretation of the reduced accuracy on cued trials ambiguous because one cannot rule out the possibility that the reduced accuracy is the result of greater information decay on cued trials (as illustrated in Figure 2). In the current study, we seek to replicate and generalize our results from Experiment 1 using a choice RT task. As in Experiment 1, and unlike previous IOR research using choice RT tasks to study the effects of IOR on accuracy, we do not use posttarget masks to hinder target identification.

Method

Thirteen people participated in the experiment for pay ($6/hr) or for course credit. The methodology of this experiment was the same as that of Experiment 1, with the exception that a response was to be made on every trial and that participants were to press the *X* key whenever the ⊗ target appeared or they were to press the *period* key whenever the ⊕ target appeared.[4] As before, there were six blocks of trials with the first and last without the response signal.[5]

Results

A repeated-measures ANOVA was performed on all measures, with TTOA (120 ms, 240 ms, 360 ms, and 480 ms) and cuing (cued and uncued) as within-participant variables. The analysis of the proportion of correct responses provides a direct measure of accuracy. While it is not essential to translate the correct percentage into the d' metric, doing so allows for a direct comparison between experiments.[6] The correct responses, although not analyzed, are presented as percentages in Table 2.

Tone RTs. The tone RTs for correct responses are presented in Table 2. The TTOA, $F(3, 36) = 14.44$, $p < .001$, and cuing, $F(1, 12) = 21.38$, $p < .001$, main effects were significant. The interaction between TTOA and cuing, $F(3, 36) = 6.12$, $p < .005$, was

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[3] Our blocked manipulation of TTOA allows for the possibility that participants adopted different strategies in different blocks (e.g., when forced to respond very quickly, as in the 120-ms TTOA). Perhaps only when a particular strategy is used is IOR expressed as a response bias (i.e., IOR increases c). At this time, however, this is purely speculation. We simply do not know whether a unique strategy is set in place in anticipation of some TTOAs, what such a strategy might be, and how such a strategy might alter the expression of IOR. However, given our earlier observations that IOR reduced false alarms (reflecting a response bias) in the absence of the response–signal methodology (e.g., Ivanoff & Klein, 2001), it is clear that the implementation of this strategy is not unique to the response–signal paradigm.

[5] Mean RTs, from the first and last blocks, were entered into a 2 (block: first and last) × 2 (cuing: cued and uncued) ANOVA. All main effects were significant: block, $F(1, 12) = 31.55$, $p < .001$, and cuing, $F(1, 12) = 25.41$, $p < .001$. The interaction was marginally significant, $F(1, 12) = 4.37$, $p = .058$, owing to the larger IOR effect in the first block (cued RT–uncued RT = 48 ms) than in the last (24 ms). Responses were also 113 ms faster in the last block than they were in the first. The analysis of errors revealed only a main effect of block, $F(1, 12) = 16.11$, $p < .005$, indicating that there were 5.10% more errors in the last block than there were in the first.

[6] Criterion (c) values can be calculated, but they are not meaningful measures in the context of the goals of this experiment because they reflect biases toward a particular response over the other response. There is no reason to expect that IOR would bias responding in this way (when each response is equiprobable), so criterion values are not considered here.

[4] When responses are defined within the same spatial axis that defines the location of a target, as is the case here with left and right responses and left and right targets, there exists the potential to observe *Simon effects* (Simon, 1990). The Simon effect refers to the performance advantage for spatially corresponding responses over spatially noncorresponding responses when the location of the target is irrelevant. Two of our reviewers suggested that we disregard the analysis of the Simon effect for fear of increasing the complexity of the results. We have complied with their suggestion, and we present these results with respect to this factor in a forthcoming report.

Table 2
Mean Tone-RTs (ms), Anticipations (%), Misses (%), and Correct Responses (%) in Experiment 2

	Target-tone onset asynchrony (ms)			
Measure	120	240	360	480
Tone-RTs (ms) for go targets				
Cued	147.0	131.0	113.0	109.0
Uncued	138.0	119.0	108.0	110.0
Anticipations (%)				
Cued	2.1	1.7	4.1	7.7
Uncued	1.8	3.5	6.4	10.7
Misses (%)				
Cued	21.5	16.3	8.8	7.9
Uncued	16.1	13.3	7.7	6.3
Correct responses (%)				
Cued	50.8	63.5	84.8	93.9
Uncued	47.8	66.1	87.4	96.4

Note. RTs = reaction times.

also significant. When we repeated the ANOVA while excluding the longest (480 ms) TTOA, the main effect of cuing was significant, $F(1, 12) = 21.77$, $p < .001$, and no longer affected by TTOA, $F(2, 24) = 2.05$, $p > .15$. This confirms the pattern seen in Table 2: Cued RTs are slower than uncued RTs except at the longest TTOA.

Anticipations. A correct anticipation is a keypress (on the task-appropriate key) to the target during the TTOA (i.e., after the target and before the tone). Incorrect anticipations were infrequent, 2%) and were not considered in the following analysis. Correct anticipations presented as percentages are shown in Table 2. The main effects of TTOA, $F(3, 36) = 19.48$, $p < .001$, and cuing, $F(1, 12) = 8.71$, $p < .05$, were significant. The TTOA effect was the result of increasing anticipations as TTOA increased. The main effect of cuing was significantly modified by TTOA, $F(3, 36) = 5.09$, $p < .005$. Because visual inspection of the data suggests that the shortest TTOA behaved differently from the others, we repeated the ANOVA excluding the 120-ms TTOA. Strongly supporting the description that at TTOAs long enough to have anticipations they are more frequent to uncued than cued targets, we found a main effect of cuing, $F(1, 12) = 9.98$, $p < .001$, and no interaction with TTOA ($F < 1$).

Misses. A miss is a response made after the response window. The mean percentages of misses are provided in Table 2. The main effects of TTOA, $F(3, 36) = 22.45$, $p < .001$, and cuing, $F(1, 12) = 15.00$, $p < .005$, were significant, as was their interaction, $F(3, 36) = 4.34$, $p < .05$. The percentages of misses decreased as TTOA increased. In addition, targets presented at the cued location ($M = 15.46\%$) were missed more often than targets presented at the uncued location ($M = 12.80\%$). There were significantly more misses for cued than for uncued targets at each TTOA except the 360-ms TTOA.

Response frequency. Response frequency is defined as the percentage of all responses (correct and incorrect) that was made within the 210-ms response window. The response frequency provides an indication of how often participants were able to respond during the response window (irrespective of accuracy). The mean response frequencies are presented in Table 2. The main effect of TTOA was significant, $F(3, 36) = 12.63$, $p < .001$, indicating that response frequency increased with TTOA. There was also an interaction between cuing and TTOA, $F(3, 36) = 6.96$, $p < .001$. Visual inspection of the data suggests that the interaction might be attributable to the effect of cuing (67.40% for cued and 72.70% for uncued) at the shortest TTOA, $t(12) = 3.35$, $p < .01$. This was confirmed by finding no main effect of cue condition and no interaction ($p > .2$) when the ANOVA was repeated excluding the 120-ms TTOA.

Sensitivity (d'). Sensitivity[7] to the target was calculated by arbitrarily assigning right responses to ⊕ targets as hits and right responses to ⊗ targets as false alarms.[8] The mean d' values are shown in Figure 5 as a function of processing lag (TTOA plus RTs for correct and erroneous responses) and cuing. The effects of TTOA, $F(3, 36) = 162.54$, $p < .001$, cuing, $F(1, 12) = 8.30$, $p < .05$, and their interaction, $F(1, 12) = 4.66$, $p < .01$, were all significant. Overall, 11 of the 13 participants demonstrated reduced sensitivity to cued targets averaged across all TTOAs. The TTOA effect was due to an increase in d' as TTOA increased. Because performance was at chance in the 120-TTOA condition, the ANOVA was repeated with this TTOA excluded. The main effect of cuing remained significant, $F(1, 12) = 13.09$, $p < .005$, while the interaction with TTOA did not, $F(2, 24) = 1.73$, $p = .20$. The interaction, then, was due to the absence of a sensitivity difference before information about the target's identity had begun to accrue.

Discussion

Replicating Experiment 1 in a different task setting, we observed lowered sensitivity to the relevant feature of the target when it appeared at the cued location. Clearly this finding supports an inhibited-attention account of the IOR effect. While the time course of IOR, measured with cue–target onset asynchrony (rather than TTOA), suggests subtle differences between IOR in choice RT and go/no-go tasks (Lupiàñez & Milliken, 1999), our results suggest that IOR in these tasks is implemented similarly.

Although there is no suitable metric comparable to c in our choice RT task, there were some findings consistent with an effect of IOR on the criterion for cued targets. First, as in Experiment 1, there were more anticipatory responses to uncued, than to the cued, targets at the late (360-ms and 480-ms) TTOAs. Additionally, and perhaps more important, the frequency of responding at the 120-ms TTOA was lower for cued targets than it was for uncued targets. While the response frequency metric is not indicative of a bias, had there been a bias against responding to cued targets, then there would surely be fewer responses (correct and erroneous) for

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[7] The analysis of the percentage of correct responses provides very similar results to the analysis of d'. There are only two differences to note. First, the cuing effect (i.e., lower accuracy for cued targets) at the 480-ms and 360-ms TTOA was significant. Second, at the 120-ms TTOA, the proportion of correct responses to cued targets was significantly higher than the proportion of correct responses to uncued targets. However, that neither the accuracy to cued or uncued targets significantly differed from chance (50%) performance makes this last finding difficult to interpret.

[8] Had the reverse assignments been calculated (i.e., left responses to ⊗ and ⊕ are designated as hits and false alarms, respectively), the sensitivity scores would have been virtually identical.

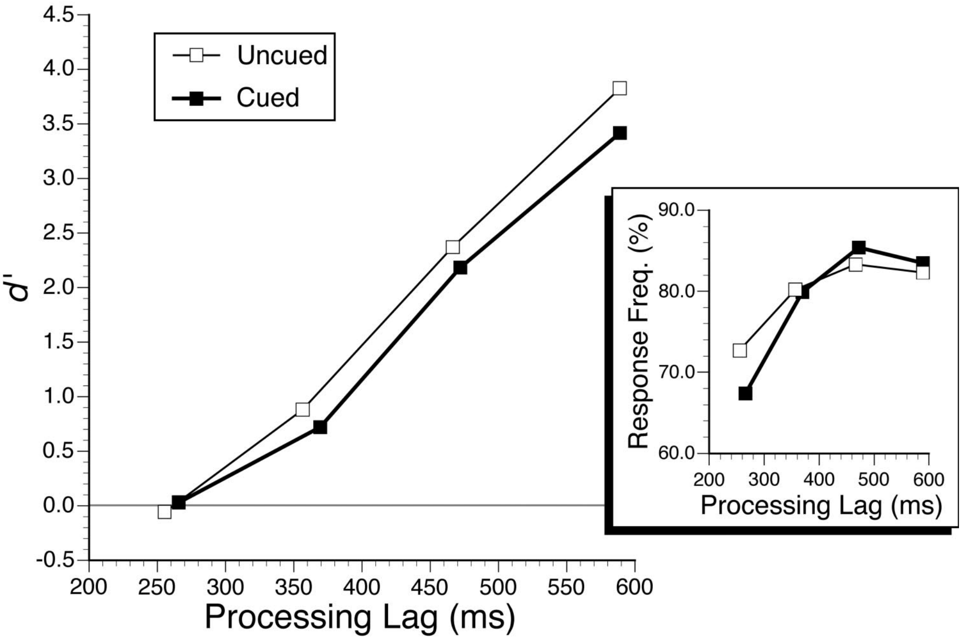

Figure 5. Sensitivity (d') to the target versus processing lag (i.e., target–tone onset asynchrony plus average RT within the response window) as a function of cuing (cued and uncued targets) in Experiment 2. Freq = frequency.

cued targets within the response window. The time course of IOR's effect on response frequency bears a close resemblance to the time course of IOR's effect on *c* such that the effects are only seen early when there is minimal sensitivity to the target (at the 120-ms TTOA). Hence, the effect of IOR on response frequency appears consistent with the criterion-shift account of IOR.

General Discussion

Here, and in previous papers (Ivanoff & Klein, 2001, 2004; Taylor & Klein, 1998, footnote 6), we have noted the ambiguity of experiments in the literature that reported a negative effect of IOR on accuracy while using posttarget masks or brief target displays (e.g., Cheal et al., 1998; Handy et al., 1999; Klein & Dick, 2002). Under these conditions, information may be decaying (Posner, 1975) and accuracy may be lower when responding is delayed (cf. Lachter & Durgin, 1999; Lachter, Durgin, & Washington, 2000). If IOR delays responding, even without directly affecting perception, then accuracy on cued trials would be lower than accuracy on uncued trials. It is, therefore, not sufficient to assess the effect of IOR on accuracy under conditions of masking: Lower accuracy on cued trials might owe to inhibited attention or a shift in the response criterion that slows responding.

The primary purpose of this study was to overcome this ambiguity by assessing the effect of IOR under different levels of speed stress while information was accumulating. This was accomplished by combining targets that remained visible up to the point that a response was made with a response signal method to force responses into different RT windows. The major findings are as follows:

1. Shortly after a target has been presented, when there is little opportunity for the processing of task-relevant target information, there is a bias against responding to cued targets.
2. Later in time, when there is some opportunity for the processing of the task-relevant feature and before target sensitivity reaches asymptotic levels, the sensitivity to cued targets is reduced.
3. RTs were often delayed by IOR even though the response signal method seeks to control and equate them across the cued and uncued conditions.

The early bias against responding to cued targets was necessarily apparent in different measures when the ability of participants to discriminate among the stimuli was measured using go/no-go (Experiment 1) and choice (Experiment 2) tasks. In Experiment 1, this was seen as a more conservative criterion (*c*) for cued than for uncued stimuli in the earliest RT window. In the same early RT window of Experiment 2, this was seen as a reduced probability of responding on cued trials. Because the dependent variables (d' and RT) for Findings 2 and 3 are the same in the two experiments, and because the methods and important patterns of results across the two experiments are similar in most important respects, we have combined individual participant's data from the two experiments ($n = 23$) and show the average IOR scores in Figure 6. Here it can be seen that for all TTOAs after the earliest one (in which accuracy is at chance), accuracy was significantly lower for cued than for uncued targets; for all TTOAs prior to the last one, RTs were significantly slower for cued than for uncued targets.

IOR lowered sensitivity to targets even when targets remained visible, and therefore, target information could continue to accrue. Therefore, our depiction of one possible effect of IOR on sensi-

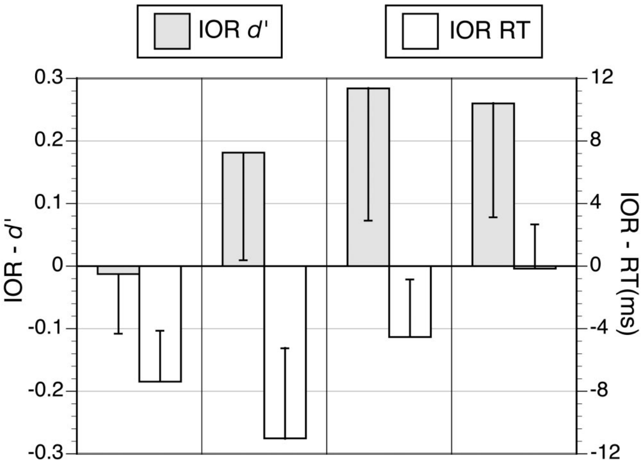

Figure 6. Inhibition of return (IOR) in accuracy (d') and reaction time (RT) are shown as a function of target–tone onset asynchrony for Experiments 1 and 2 combined. The 95% inferential confidence intervals can be used to determine the degree to which each measure of IOR (uncued minus cued) is significant (when the bar overlaps zero, the effect is not significant). Note that sensitivity (filled bars) is indexed to the scale on the left, and RT (empty bars) is indexed to the scale on the right. A positive score for d' and a negative score for RT reflect worse performance on cued than for uncued trials.

tivity to decaying targets (see Figure 2) does fully explain the negative effect of IOR on sensitivity. While this depiction remains a possibility for data-limited targets, given the results in Figure 6, it would be more parsimonious to assume that IOR generally negatively affects attention, perception, or both.

The distinction between the attentional and motor effects of IOR has usually been one that focuses on whether saccades are used to generate or measure IOR (e.g., Hunt & Kingstone, 2003; Kingstone & Pratt, 1999; Taylor & Klein, 1998, 2000). Here we have found evidence for attentional and motor effects of IOR in the same response modality and task. Moreover, our analysis specifically suggests that "motor" IOR may be implemented as a criterion-shift mechanism, not unlike that proposed by Klein and Taylor (1994). Next we explore some possible relations between the early and late effects of IOR upon bias and sensitivity, respectively.

How Might the Effects of IOR on the Criterion and Sensitivity Be Related?

Independent and unrelated. Whether IOR affects the criterion or attention has been reported to depend on the response modality (e.g., Kingstone & Pratt, 1999; Taylor & Klein, 2000), motoric IOR is expressed when saccades are made and IOR affects attention when they are withheld. This pattern of results has led to a consensus in the literature that the attention and motor effects of IOR are independent: Under some conditions, IOR will act upon the response criterion; under other conditions, IOR will act upon attention. Our results, demonstrating that IOR affects *c* early and d' late, suggest that IOR may be expressed differently depending on response speed demands. When responses are to be made quickly, and the quality of stimulus evidence is poor, IOR is seen as a criterion shift. As the quality of stimulus evidence improves, IOR begins to act upon attention, thereby increasing errors and slowing RTs for targets at cued locations. While our response signal methodology was successful in demonstrating and separating these components, in the typical RT task, IOR may manifest as both a criterion shift and as inhibited attention. In other words, in tasks in which speed and accuracy are equally stressed, both components of IOR may operate within different components of the RT distribution or perhaps both components may be operating simultaneously, but not necessarily equally, on every trial. A factor that naturally speeds RTs (and reduces the quality of stimulus evidence), however, may reveal more of the criterion-shift component of IOR; whereas a factor that encourages slower responding (and emphasizes a deeper processing of the stimulus) may reveal more of the attentional component of IOR. Given that saccadic RTs are often faster than manual RTs, the possibility exists that whether IOR affects motoric or attentional processes depends on the time in which it has the potential to operate.

Independent, but related. Early in processing, when sensitivity is very low, IOR increases the criterion. This is an important finding that extends our earlier work (Ivanoff & Klein, 2001, 2004). During the early processing of the target, IOR resembles an expectancy whereby, in the absence of task-relevant target information, the cued location is disfavored over novel uncued locations. Perhaps this finding is not unlike the spontaneous alternation behavior observed in some species (e.g., see Lalonde, 2002, for a review). In a T maze, rats (and a variety of other species) tend to avoid the arm of the T maze that they had entered on a previous trial. Note that, in a T maze, the rat initially has no information regarding the whereabouts of the reward. Spontaneous alternation is thought to promote exploration. Likewise, IOR has been argued to facilitate visual exploration (Klein & MacInnes, 1999). Once IOR disregards a location for further processing, alternate locations might be attended for forthcoming activity. Thus, in this respect, the effects of IOR on the response criterion and attention are independent, but they operate cooperatively to achieve the same goal.

Dependence. Kahneman (1973), expanding ideas put forth by Broadbent (1971), argued that criterion shifts (viz., a pigeonholing process or what he referred to as "perceptual readiness") can affect perception. According to Kahnemen, it is precisely under conditions in which the quality of stimulus information is poor that biases are best observed. He went on to state that with "suitable analyses . . . it is possible to distinguish between perceptual changes which represent a shift of criteria and other perceptual changes which represent alternations of the sensitivity of perceptual analysis" (Kahnemen, 1973, p. 96). The perceptual changes that accompany IOR may not necessarily result from inhibited perception or attention, per se, but may be the result of an earlier bias against cued targets.

How might an early criterion shift cause later changes in sensitivity? In an unpublished technical report, Shulman and Posner (1988) suggested that selection may operate by altering criterion levels. If the criterion level is raised at an early stage of processing, then information accumulating there will be less likely, or slower, to pass onto later processing stages. Thus, "Selection might be accomplished by only passing activity that exceeds a certain criterion value . . . [and] . . . to the extent that selection controls access to mechanism[s] that change signal/noise ratios, selection will produce d' changes" (Shulman &Posner, 1988, pp. 8–10). Extending these ideas about selective attention to the mechanism of IOR, it is possible that by initially biasing responding away from cued targets, IOR may discourage selection of targets presented at cued locations, thus causing the sensitivity difference we have observed later in target processing. Thus, following Shulman and Posner's ideas, the early effect of IOR on criteria and the later effect upon sensitivity may be considered jointly, and we offer the following speculative linkage: A raised criterion at an early processing stage may function to reject locations for further processing by slowing or delaying information accrual at later stages. Whether the early effect of IOR upon the criterion has any mediating influence on IOR's negative effect on d' is an empirical issue worthy of further exploration.

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Received February 23, 2006
Revision received February 23, 2006
Accepted February 23, 2006 ■