Research Report

PROMOTING NOVELTY IN VISION:
Inhibition of Return Modulates Perceptual-Level Processing

Todd C. Handy, Amishi P. Jha, and George R. Mangun
Department of Psychology and Center for Neuroscience, University of California, Davis

Abstract—*To facilitate visual search of complex scenes, information arising from recently attended locations is subject to a selective inhibition in processing known as inhibition of return (IOR). Although the mechanisms of IOR remain unresolved, both motor and perceptual influences have been proposed based on reaction time (RT) studies. Here we report the results of two reflexive cuing studies in which signal detection methodology was employed to directly examine the effects of IOR on perception. IOR was found to be associated with a significant reduction in the accuracy of target discriminations at recently attended locations. Further, these effects of IOR on response accuracy were independent of whether emphasis was placed on the speed of responding. These results provide the first direct evidence that IOR can affect the perceptual quality of visual processing.*

Humans are remarkably efficient at orienting to relevant events in the visual world. Effective orienting is subserved in part by a temporary inhibition in neural processing that is associated with recently attended locations in the visual field. This inhibitory phenomenon—known as inhibition of return (IOR)—lasts for several seconds, and follows a brief facilitation in processing attributable to reflexive attention (e.g., Posner & Cohen, 1984; for a review, see Taylor & Klein, in press). IOR can be characterized as a selective inhibition in processing because only information arising in recently attended locations is inhibited (see also Tipper, Weaver, Jerreat, & Burak, 1994). Although it is generally agreed that IOR promotes attending to novel events in the visual field by inhibiting recently attended information, there has been contentious debate over whether IOR can occur at perceptual-level stages of processing.

Initial efforts to examine perceptual effects in IOR involved the use of temporal-order judgments (TOJs), during which subjects must decide which of two presented stimuli occurred first. Both Maylor (1985) and Posner, Rafal, Choate, and Vaughn (1985) found that IOR did not affect TOJs, which was taken as evidence that IOR does not involve perceptual inhibition because the temporal characteristics of the visual input remained unperturbed. Although Gibson and Egeth (1994) cast doubt on these conclusions, showing that IOR can affect TOJs under certain experimental conditions, their positive results have now been questioned (Klein, Schmidt, & Müller, 1998). As a result, the data from studies of TOJs remain equivocal on whether IOR can affect perceptual processing (see also Schmidt, 1996).

Perceptual effects in IOR have also been examined using reaction time (RT) paradigms. In similar studies, Abrams and Dobkin (1994) and Rafal, Egly, and Rhodes (1994) measured saccadic RTs as a function of whether or not the imperative stimulus for moving the

eyes required the detection of a nonfoveal target. Although Abrams and Dobkin and Rafal et al. both concluded that IOR can inhibit stimulus detection, motor-level inhibition was also implicated in their results (see Klein & Taylor, 1994; Rafal & Henik, 1994), and both studies were faced with the problem of dissociating perceptual from motor effects. As a result, although Abrams and Dobkin and Rafal et al. agreed that perceptual-level IOR can occur, they ultimately disagreed over the specific conditions in which it is manifest, underscoring the inherent difficulty of ruling out motor-level explanations of IOR when using RT measures (see, e.g., Müller & von Mühlenen, 1996).

The question thus remains: Can IOR affect perceptual-level processing? In the following study, we adopted a novel approach to this question based on signal detection measures of perceptual sensitivity (e.g., Macmillan & Creelman, 1991). Because these measures reflect the accuracy of target responses, they should remain relatively unaffected by any motor-level inhibition that may contaminate RT measures of IOR, thus providing a more direct test of whether IOR can modulate perceptual processing.

EXPERIMENT 1

Experiment 1 was a reflexive attentional cuing study designed to investigate the effects of IOR on perceptual processing using the signal detection measure d'. If IOR can modulate perceptual processing, d' scores should be lower at cued than at uncued locations, given a sufficient delay between cue and target. However, d' scores should be higher at cued than at uncued locations at short delays between cue and target, because of the initial orienting of attention to the cued location (e.g., Posner & Cohen, 1984). Such a data pattern would rule out the possibility that any IOR effects are due to sensory interactions between the cue and target (e.g., forward masking).

Method

The trial sequence and timing are shown in Figure 1. Each trial started with the presentation of a nonfoveal (peripheral) cue to the left or right of fixation. In the long-delay condition, this cue was followed by a second (central) cue presented at fixation (see Posner & Cohen, 1984). Following the last cue of the trial, a small target bar (with either a vertical or a horizontal orientation) was presented in one of the two peripheral locations, and immediately masked. The target locations, one in each upper visual-field quadrant, were demarcated by the outlines of 1.5° square boxes. These boxes were located 3.7° (to center) from fixation and 2.5° (to center) above the horizontal meridian. The nonfoveal cue was a brief brightening of one of the two boxes. The central cue was a 0.33° filled white square; the target bar was yellow, 2 pixels wide, and from 3 to 18 pixels long (adjustments in length are explained later). The mask was 1.5° square and consisted of a set of random yellow shapes of various fill textures.
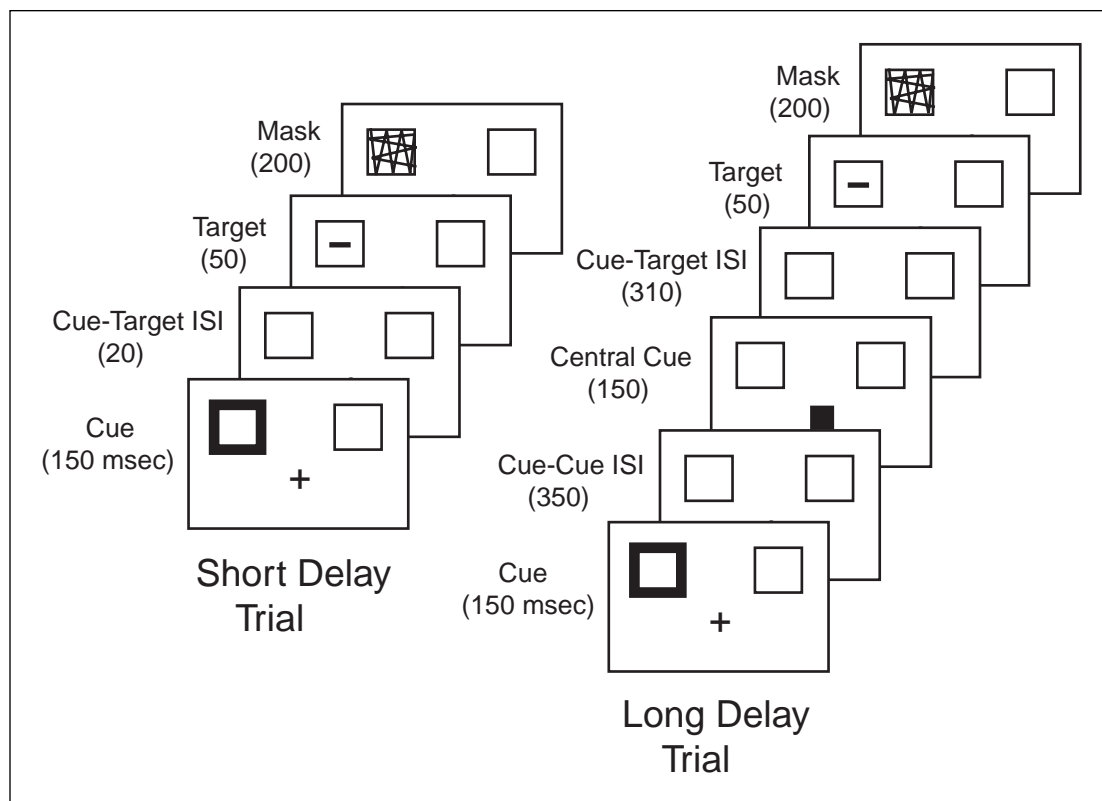

157

Fig. 1. Sequence and timing of stimulus events on short- and long-delay trials in both Experiments 1 and 2. A cued trial for the left location is shown, and stimuli are in reverse contrast to those used in the experiment. On every trial, the target stimulus was equally likely to be a vertical or a horizontal bar. The interval between trials (mask offset to peripheral cue onset) was 2,500 ms. ISI = interstimulus interval.

Subjects were required to make a discrimination judgment of the target bar's orientation (i.e., vertical or horizontal) at the masked location, and to respond only to bars of one designated orientation (the *target orientation*, which was counterbalanced across subjects). A hit was defined as a response on trials with the target orientation present, and a false alarm was defined as a response on trials with the target orientation absent. The nonfoveal cues were nonpredictive of the target bar's location, and target versus nontarget orientation was equiprobable. A *cued* trial was defined as a target bar at the cued peripheral location, and an *uncued* trial was defined as a target bar at the uncued peripheral location. On 20% of the trials (catch trials), only a cue was presented, in order to eliminate anticipatory responses. Accuracy and speed of response were emphasized equally to the subjects.

Twenty subjects were each run in individual sessions consisting of 15 blocks of 40 trials (32 cued and 8 catch trials per block), with the cued trials equally split (but randomly varying) between short and long cue-target delays. At the beginning of each session, the subject was given extensive practice in the task until near-perfect performance was established with relatively large, easy-to-discriminate target bars. Prior to data collection, the target length was reduced until performance was approximately 75% correct overall, in order to minimize the possibility of floor or ceiling effects in accuracy. During data collection, target length was adjusted as necessary between trial blocks in order to maintain approximately this level of performance. Eye movements were monitored by electro-oculograms; trials with movement

and blink artifacts were removed prior to data analysis (see Handy, Kingstone, & Mangun, 1996).

Results and Discussion

Mean RTs, d's, betas, hit rates, false alarm rates, and A's are presented in Table 1;[1] RTs and d's are plotted in Figure 2a. Repeated measures analyses of variance with factors of cue-target delay (170 vs. 960 ms) and cue condition (cued vs. uncued) showed significant delay-by-cue interactions for both RT ($F[1, 19] = 19.87$, $MSE = 1,413.92$, $p < .001$) and d' ($F[1, 19] = 7.58$, $MSE = 0.21$, $p < .05$), but no main effects in either measure (all ps > .05).[2] One-tailed t tests confirmed that at the

---

1. A' is a signal detection measure of accuracy that, unlike d', does not assume normal distributions of signal and noise. Rather, it is an estimate of $P(A)$ (the area underneath a receiver operating characteristic curve) that is based on a single pair of hit and false alarm rates (see Macmillan & Creelman, 1996). A' is reported here to ensure that any apparent effects of IOR on response accuracy are not an artifact of the assumptions underlying d'.

2. The analyses of variance for RT and d' in both Experiments 1 and 2 also included a factor of visual field. However, no significant effects of visual field or interactions involving visual field were found in either experiment (all ps > .05). In both experiments, the statistics for A' paralleled those for d'; for brevity, they are not reported here. Finally, no significant effects on beta were found in either experiment.

Todd C. Handy, Amishi P. Jha, and George R. Mangun

Table 1. *Mean reaction time,* d*', beta, hit rate, false alarm rate, and* A*' across subjects in Experiment 1 as a function of cue-target delay and cue condition*

Cue condition	Measure					
	Reaction time (ms)	d'	Beta	Hit rate	False alarm rate	A'
170-ms delay						
Cued	515	1.63	1.52	.749	.202	.857
	(66)	(0.41)	(1.55)	(.11)	(.11)	(.07)
Uncued	531	1.36	1.85	.650	.192	.813
	(76)	(0.66)	(1.88)	(.16)	(.10)	(.11)
960-ms delay						
Cued	526	1.42	1.21	.725	.235	.821
	(60)	(0.54)	(0.61)	(.13)	(.13)	(.14)
Uncued	493	1.60	1.32	.759	.217	.855
	(74)	(0.53)	(0.62)	(.10)	(.15)	(.08)

Note. Standard deviations are in parentheses.

short cue-target delay, RT was faster ($t[19] = -1.96$, $SE = 8.04$, $p < .05$) and d' higher ($t[19] = 2.75$, $SE = 0.10$, $p < .01$) for targets at the cued than at the uncued location. In contrast, at the long delay, RT was slower ($t[19] = 6.08$, $SE = 5.43$, $p < .001$) and d' was lower ($t[19] = 2.28$, $SE = 0.08$, $p < .05$) for targets at the cued than at the uncued location.[3]

These results show that discrimination accuracy was reduced at the cued versus uncued location at the long cue-target delay—a pattern consistent with the inhibitory effects of IOR. Because discriminations were initially more accurate at the cued than at the uncued location (at the short cue-target delay), the inhibitory effect at long delays cannot be attributed to simple forward masking between the cue and target. However, in Experiment 1, subjects were instructed to respond both accurately and quickly. It has been argued that the processing stage indexed by an accuracy measure may vary as a function of specific task parameters (e.g., Santee & Egeth, 1982). To eliminate any concerns that speeded responding may have introduced nonoptimal conditions for measuring response accuracy—and that our d' results may thus be an unreliable index of perceptual sensitivity—we performed a second experiment in which only the accuracy of responding was emphasized to subjects.

EXPERIMENT 2

Experiment 2 examined whether the effects of IOR on discrimination accuracy in Experiment 1 were an artifact of the speeded response requirement imposed on the subjects. Experiment 2 was identical to Experiment 1, except that subjects were instructed to respond as accurately as possible, with the only temporal constraint being that a

response had to be made within the 2.5-s interval between trials. This time span allowed for unhurried responses, while also avoiding possible memory confounds associated with the decay of perceptual information during delayed responses (see Luck et al., 1994). Fifteen subjects participated.

Mean RTs, d's, betas, hit rates, false alarm rates, and A's are presented in Table 2; RTs and d's are plotted in Figure 2b. Comparing RTs in Table 2 and Table 1 shows that, overall, subjects were slower in responding in Experiment 2 than Experiment 1. Repeated measures analyses of variance with factors of cue-target delay (170 vs. 960 ms) and cue condition (cued vs. uncued) showed a significant delay-by-cue interaction for both RT ($F[1, 14] = 6.97$, $MSE = 5,259.59$, $p < .05$) and d' ($F[1, 14] = 20.92$, $MSE = 0.08$, $p < .001$), with no main effects in either measure (all ps $> .05$). One-tailed t tests confirmed that at the short cue-target delay, d' was higher ($t[14] = 2.51$, $SE = 0.12$, $p < .05$) at the cued than at the uncued location, whereas at the long cue-target delay, d' was higher at the uncued than at the cued location ($t[14] = -2.93$, $SE = 0.07$, $p < .01$).[4]

Experiment 2 replicated the key result of Experiment 1 by showing that discrimination accuracy was lower at the cued than at the uncued location at the long cue-target delay. These findings indicate that the effect of IOR on d' in Experiment 1 was not an artifact of pressing subjects on the speed of their responses.

CONCLUSIONS

We have shown that when visual attention is reflexively oriented to nonfoveal cues, following sufficient delay between cue and target, target discriminations are less accurate at cued than uncued locations. This effect on discrimination accuracy cannot be attributed to forward masking between the cue and target because target discriminations were initially better at the cued than at the uncued location (i.e., at short cue-target delays). The results of Experiment 2 demonstrate that the inhibitory effect on accuracy does not depend on whether subjects emphasize speed in their responses. Moreover, because the critical dependent measures were based on response accuracy, motor-level explanations of the data can be ruled out, unlike in prior RT studies (see Klein & Taylor, 1994; Rafal & Henik, 1994). As a result, we conclude that IOR can modulate perceptual-level processing.

The current findings rest on the critical assumption that d' is a reliable index of perceptual sensitivity, but what evidence supports this position? Luck et al. (1994) have shown that in spatial cuing tasks, variations in d' co-occur with modulations of sensory-evoked processing in extrastriate visual cortex. Further, the paradigm used by Luck et al. was carefully designed to eliminate possible confounds in the accuracy data associated with memory decay and decision biases. By utilizing a similar paradigm in our experiments, we obtained direct support for a perceptual-level effect on d', and also eliminated critical postperceptual interpretations of the data (see also Santee & Egeth, 1982).

Given that IOR can modulate perceptual sensitivity, how might these effects be manifest? Our data are not inconsistent with the

---

3. The t tests reported are one-tailed because the direction of the effect was explicitly predicted at both stimulus onset asynchronies on theoretical grounds (e.g., Posner & Cohen, 1984) and on the basis of results of two pilot studies (total $N = 50$) similar to Experiment 1.

---

4. RT was faster at the cued than at the uncued location during the short delay, $t(14) = -1.75$, $SE = 14.25$, $p < .05$. In contrast, at the long cue-target delay, RT was not significantly slower at the cued than at the uncued location ($p > .05$), likely reflecting an overall increase in RT variance associated with delayed responding. However, the critical point is that an IOR effect remained in d' when no emphasis was placed on the overall speed of response.
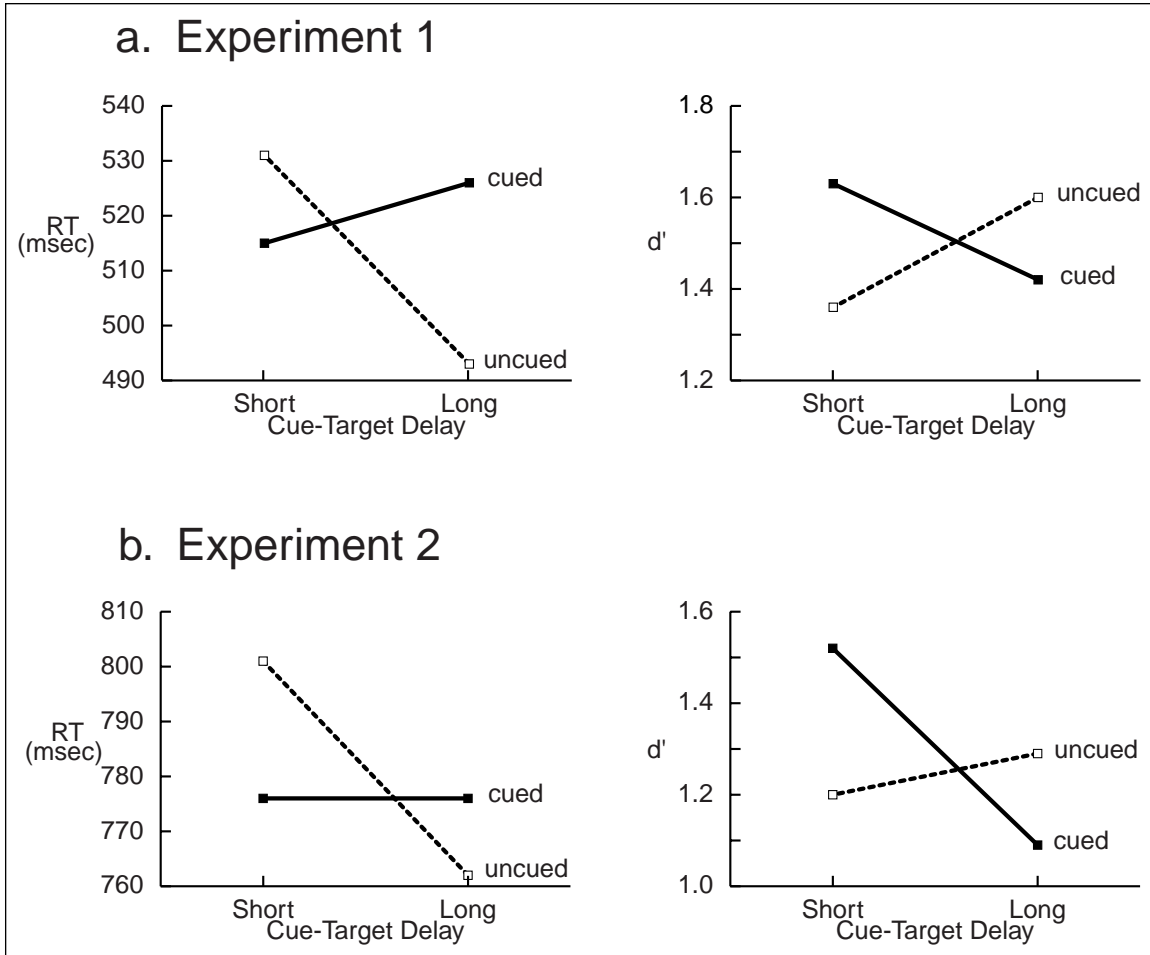
Fig. 2. Mean reaction times (RTs, left) and *d*'s (right) from Experiment 1 (a) and Experiment 2 (b), plotted as a function of cue-target delay and cue condition.

Table 2. *Mean reaction time,* d'*, beta, hit rate, false alarm rate, and* A' *across subjects in Experiment 2 as a function of cue-target delay and cue condition*

Cue condition	Reaction time (ms)	*d*'	Beta	Hit rate	False alarm rate	A'
			Measure			
		170-ms delay				
Cued	776	1.52	1.20	.759	.244	.831
	(152)	(0.62)	(0.80)	(.12)	(.12)	(.09)
Uncued	801	1.20	1.32	.650	.230	.798
	(182)	(0.47)	(0.66)	(.15)	(.09)	(.09)
		960-ms delay				
Cued	776	1.09	1.01	.696	.297	.786
	(161)	(0.44)	(0.20)	(.10)	(.08)	(.11)
Uncued	762	1.29	0.91	.762	.294	.822
	(163)	(0.34)	(0.17)	(.07)	(.08)	(.06)

Note. Standard deviations are in parentheses.

possibility that IOR may slow the rate at which perceptual information accumulates (Abrams & Dobkin, 1994; Gibson & Egeth, 1994; Rafal et al., 1994). However, in Experiment 2, we showed that when discrimination judgments are delayed, accuracy is still greater for targets at the uncued location, suggesting that IOR can also affect the total amount or quality of perceptual information that accumulates. In this regard, the dual effects of IOR on perceptual processing may closely parallel the perceptual influences associated with spatial attention, which has been shown to modulate both the rate at which perceptual information is encoded (e.g., Reinitz, 1990) and the subsequent quality of that information (e.g., Downing, 1988; Handy et al., 1996; Luck et al., 1994).

Although the possible role of attention in IOR is an unresolved issue (e.g., Chelazzi et al., 1995; Müller & von Mühlenen, 1996; Rafal, 1996), our data nevertheless suggest that IOR can affect perceptual processing in ways similar to attention (see O'Donnell & Pratt, 1996; Pratt, Kingstone, & Khoe, 1997; Reuter-Lorenz, Jha, & Rosenquist, 1996). Further, our data also clearly demonstrate that—contrary to some suggestions (e.g., Terry, Valdes, & Neill, 1994)—IOR can occur in discrimination tasks, as previously reported by Pratt (1995). In conclusion, our findings present the first clear evidence that IOR promotes the efficient examination of the visual world by highlighting novel perceptual events.

Todd C. Handy, Amishi P. Jha, and George R. Mangun

REFERENCES

Abrams, R.A., & Dobkin, R.S. (1994). Inhibition of return: Effects of attentional cuing on eye movement latencies. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 467–477.

Chelazzi, L., Biscaldi, M., Corbetta, M., Peru, A., Tassinari, G., & Berlucchi, G. (1995). Oculomotor activity and visual spatial attention. *Behavioural Brain Research, 71,* 81–88.

Downing, C.J. (1988). Expectancy and visual-spatial attention: Effects on perceptual quality. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 188–202.

Gibson, B.S., & Egeth, H. (1994). Inhibition and disinhibition of return: Evidence from temporal order judgments. *Perception & Psychophysics, 56,* 669–680.

Handy, T.C., Kingstone, A., & Mangun, G.R. (1996). Spatial distribution of visual attention: Perceptual sensitivity and response latency. *Perception & Psychophysics, 58,* 613–627.

Klein, R.M., Schmidt, W.C., & Müller, H.K. (1998). Disinhibition of return: Unnecessary and unlikely. *Perception & Psychophysics, 60,* 862–872.

Klein, R.M., & Taylor, T.L. (1994). Categories of cognitive inhibition with reference to attention. In D. Dagenbach & T.H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 113–150). San Diego: Academic Press.

Luck, S.J., Hillyard, S.A., Mouloua, M., Woldorff, M.G., Clark, V.P., & Hawkins, H.L. (1994). Effects of spatial cuing on luminance detectability: Psychophysical and electrophysiological evidence for early selection. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 887–904.

Macmillan, N.A., & Creelman, C.D. (1991). *Detection theory: A user's guide.* New York: Cambridge University Press.

Macmillan, N.A., & Creelman, C.D. (1996). Triangles in ROC space: History and theory of "nonparametric" measures of sensitivity and response bias. *Psychonomic Bulletin & Review, 3,* 164–170.

Maylor, E. (1985). Facilitatory and inhibitory components of orienting in visual space. In M.I. Posner & B.B. Marin (Eds.), *Attention and performance XI* (pp. 189–204). Hillsdale, NJ: Erlbaum.

Müller, H.J., & von Mühlenen, A. (1996). Attentional tracking and inhibition of return in dynamic displays. *Perception & Psychophysics, 58,* 224–249.

O'Donnell, C., & Pratt, J. (1996). Inhibition of return along the path of attention. *Canadian Journal of Experimental Psychology, 50,* 386–392.

Posner, M.I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D.G. Bouwhuis (Eds.), *Attention and performance X* (pp. 531–556). Hillsdale, NJ: Erlbaum.

Posner, M.I., Rafal, R.D., Choate, L., & Vaughn, J. (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 to location- and identity-based choice decision tasks. *Perception & Psychophysics, 59,* 964–971.

Rafal, R.D. (1996). Visual attention: Converging operations from neurology and psychology. In A.F. Kramer, M.G.H. Coles, & G.D. Logan (Eds.), *Converging operations in the study of visual selective attention* (pp. 139–192). Washington, DC: American Psychological Association.

Rafal, R.D., Egly, R., & Rhodes, D. (1994). Effects of inhibition of return on voluntary and visually guided saccades. *Canadian Journal of Experimental Psychology, 48,* 284–300.

Rafal, R.D., & Henik, A. (1994). The neurology of inhibition: Integrating controlled and automatic processes. In D. Dagenbach & T.H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 1–52). San Diego: Academic Press.

Reinitz, M.T. (1990). Effects of spatially directed attention on visual encoding. *Perception & Psychophysics, 47,* 497–505.

Reuter-Lorenz, P.A., Jha, A.P., & Rosenquist, J.N. (1996). What is inhibited in inhibition of return? *Journal of Experimental Psychology: Human Perception and Performance, 22,* 367–378.

Santee, J.L., & Egeth, H.E. (1982). Do reaction time and accuracy measure the same aspects of letter recognition? *Journal of Experimental Psychology: Human Perception and Performance, 8,* 489–501.

Schmidt, W.C. (1996). Inhibition of return is not detected using illusory line motion. *Perception & Psychophysics, 58,* 883–898.

Taylor, T.L., & Klein, R.M. (in press). On the causes and effects of inhibition of return. *Psychonomic Bulletin & Review.*

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.