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Inhibition of Return Is Not Reflexive

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Searching for objects is perhaps the most common visual task we perform. Whenever we look for a face in a crowd, or an item in a container, or a street name on a map, we are carrying out a serial search routine. And search is usually so rapid that researchers have only recently begun to appreciate the complexity of the operations involved. The discovery of the *inhibition-of-return* effect (Posner & Cohen, 1984) has provided some important clues about serial search. Inhibition of return (IOR) appears to be associated with a procedure that many researchers believe allows us to keep track of objects when looking through a large collection of them. More specifically, some type of marking operation seems to occur in order to make the performance of tasks involving serial inspection more efficient, and the IOR effect may be caused by this marking.

If you were asked about the number of dots in Figure 1, your strategy might be to count them by beginning on the left and moving to the right. As you did this, you would adjust your tally while somehow keeping track of the dots once they have been inspected. Without some means of keeping counted and uncounted dots distinct, the task would be difficult to perform efficiently and accurately. Counting therefore involves a serial analysis that maintains the locations of previously inspected objects in some way.

Higher-level vision is, for the most part, serial in nature (Ullman, 1997). The eye movements we make to foveate and analyze an object of interest are physically constrained to a single location at a time, and there is also compelling evidence that the focus of visual attention is unitary and constrained to a single location (see, e.g., Wright & Ward, this volume). The frequency and speed of this serial analysis (we can move our eyes and attentional focal point several times in less than one second) requires that an associated marking mechanism operate rapidly and automatically without the need for a conscious decision to keep track of each inspected location. Such a mechanism would operate at an early stage of visual processing, and maintain location information independently of the attentive analysis of the currently in-
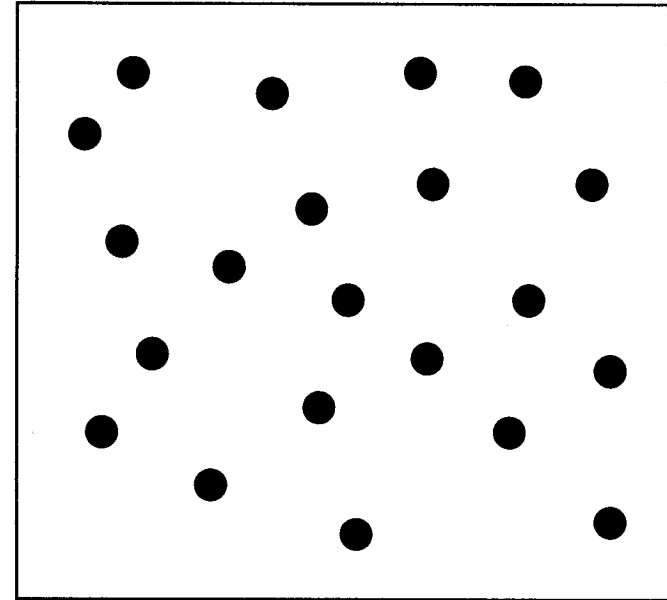
Figure 1: When counting a cluster of dots, we seem to keep track of those that have already been tallied with some form of marking operation.

spected object. The IOR effect we describe in this chapter appears to be associated with this type of marking mechanism.

Researchers generally agree that IOR is somehow involved in the selection of locations to be searched. Posner and his colleagues (e.g., Clohessy, Posner, Rothbart, & Vecera, 1991; Harman, Posner, Rothbart, & Thomas-Thrapp, 1994; Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985) proposed that it biases saccadic eye movements away from recently sampled locations and toward novel locations, thereby making visual search more efficient. Eye movement biasing proposals make good sense from an efficiency standpoint because saccades are relatively time consuming – saccade execution can last up to 50 ms and this is followed by a refractory period of up to 200 ms during which another saccade cannot be made (Abrams & Dobkin, 1994).

The IOR effect is typically obtained in the laboratory in one of two ways. *Saccade-induced IOR* occurs when observers make a saccadic eye movement to one location and then to another. When a target is presented at the first fixated location, detection response times are slower than would be the case if it was presented elsewhere (e.g., Posner et al., 1985). The increase in response time is usually attributed to some form of inhibition related to eye movement programming (e.g., Harman et
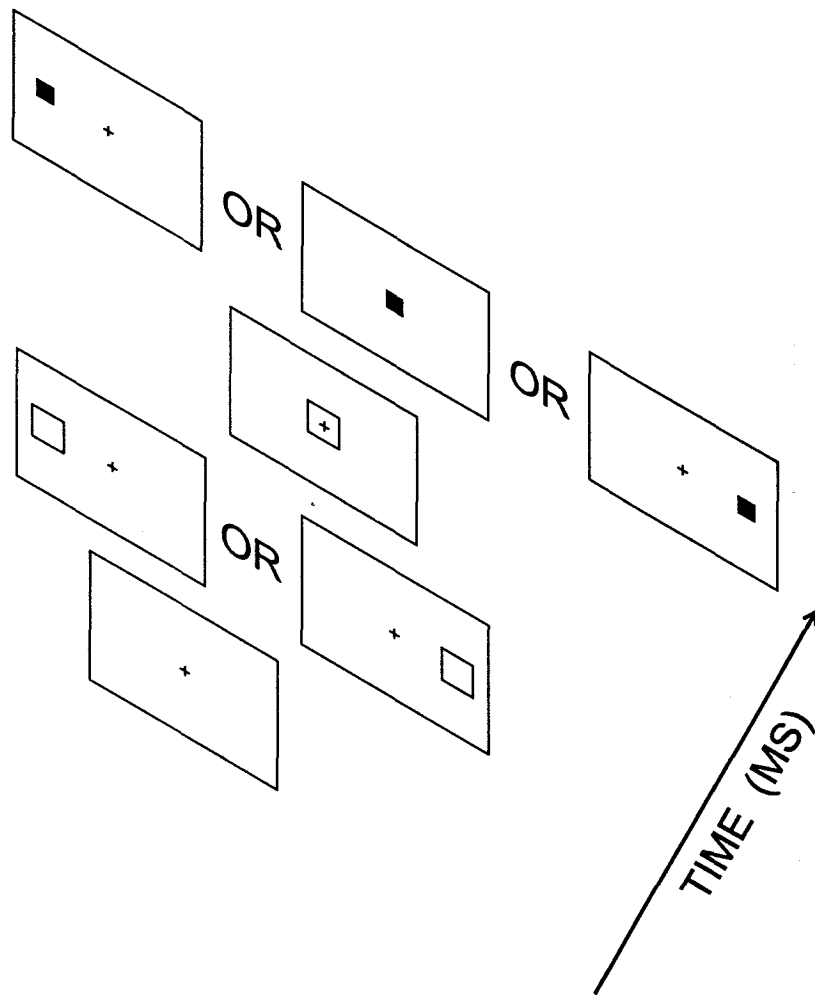
Figure 2: Typical display used for generating stimulus-induced inhibition of return (IOR). Outline boxes serve as location cues at the peripheral and central locations.

al., 1994; Rafal, Egly, & Rhodes, 1994). Stimulus-induced IOR can be obtained by presenting two successive abrupt-onset stimuli; one at a peripheral location followed 200 ms later by one at the central location. And 200 ms after the presentation of the second cue, a target is either presented at the first cued location, the second cued location, or an un-cued location (see Figure 2). As with saccade-induced IOR, detection response times are significantly slower for targets presented at the first cued location than for those presented elsewhere.

There are several proposals about how the visual system produces IOR. Maylor (1985; Maylor & Hockey, 1987) claimed that in order for IOR to occur, a channel of focused attention must first be directed to the location in question. On the other hand, Posner and Cohen (1984) claimed that it occurs as the result of sensory events (e.g., the onset of a direct location cue) that trigger the activation of a facilitative and an inhibitory component. The facilitative effect initially masks the inhibitory effect, and IOR occurs when the former attenuates and the inhibitory effect then becomes dominant. Rafal, Calabresi, Brennan, and Sciolto (1989) and Tassinari, Biscaldi, Marzi, and Berlucchi (1989) claimed that IOR is caused by some aspect of oculomotor system activation. Abrams and Dobkin (1994) proposed that saccade-induced IOR is due to inhibition of oculomotor processes, whereas stimulus-induced IOR is due to inhibition of both oculomotor and stimulus-detection processes. Thus, there is currently some disagreement about the roles that attention and saccadic eye movement programming play when IOR occurs.

Spatial Indexing and Inhibition of Return

In this chapter, we suggest an account of IOR that is not purely attentional and not purely oculomotor. It is based on the idea of multiple spatial indexing. One motivation for this account is a finding that IOR can occur at more than one location at the same time. Posner and Cohen (1984) were among the first to report *multiple-location IOR*. They conducted an experiment in which direct cues were presented simultaneously at two peripheral locations and then, 200 ms later, a distractor stimulus was presented in the centre of the display. IOR occurred when a target was presented at either peripherally cued location. And, more important, the magnitude of IOR on double-cue trials was not significantly different than that on single-cue trials. It is difficult to explain this multiple-location IOR effect purely in terms of attentional processing because, as mentioned previously, there is a general consensus that the focus of visual attention cannot be divided between two or more locations. Therefore, Posner and Cohen (1984) claimed that multiple-location IOR is not the result of attending to the direct cued locations in sequence with a single channel of focused attention but instead is the result of the onsets of the cues themselves or, in their terms, "the energy change present at the cued positions" (p. 539).

This claim was challenged when a replication study yielded different results (Maylor, 1985). In particular, IOR magnitude on simultaneous double-cue trials was roughly 50% of that on single-cue trials. This suggested that, on any given double-cue trial, only one of the two simultaneously cued locations was actually inhibited. It was concluded that IOR is the result of a serial attentive analysis of the cued
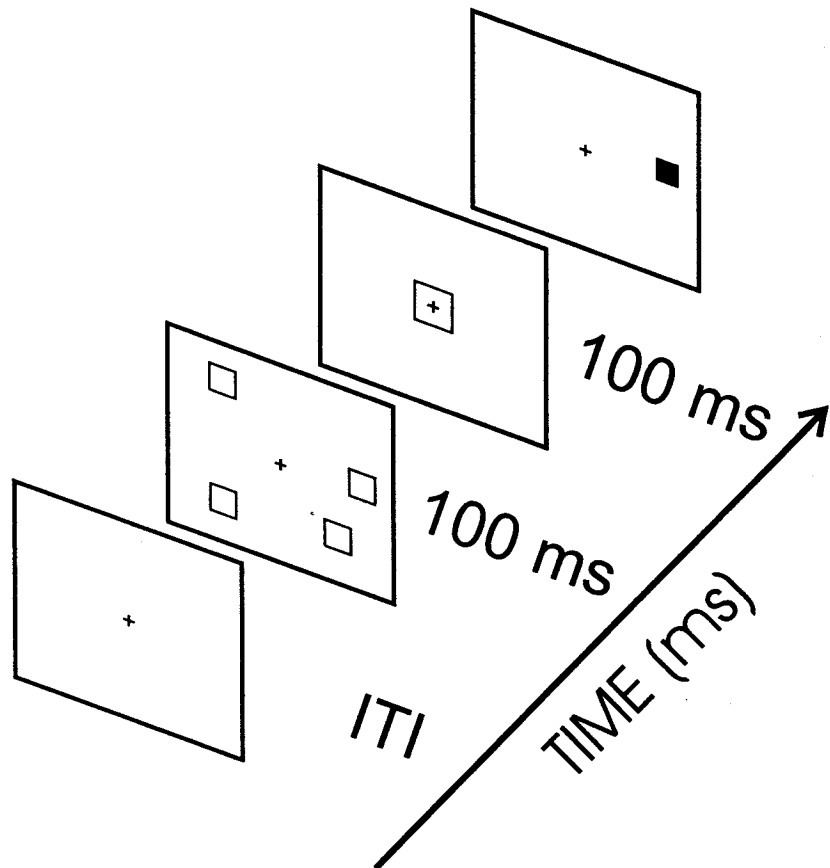
Figure 3: Simultaneous location cueing display used for generating the multiple-location inhibition-of-return (IOR) effect.

locations. This is quite a different claim than Posner and Cohen's (1984) idea that IOR is the result of a sensory analysis of the cued locations that is triggered by cue onsets.

In the early 1990s, we conducted several studies to determine the extent to which IOR is due to sensory or attentional processes (Wright & Richard, 1993, 1994, 1996a). Like Posner and Cohen (1984), we compared the IOR magnitude associated with single-cue and multiple-cue conditions (see Figure 3). We found that IOR occurred with roughly equal magnitude following simultaneous single, double, triple, and quadruple cues (see Figure 4). IOR at four locations is particularly difficult to account for in terms of a serial attentive analysis of cued locations and its occurrence suggests that IOR is mediated by parallel sensory analysis.
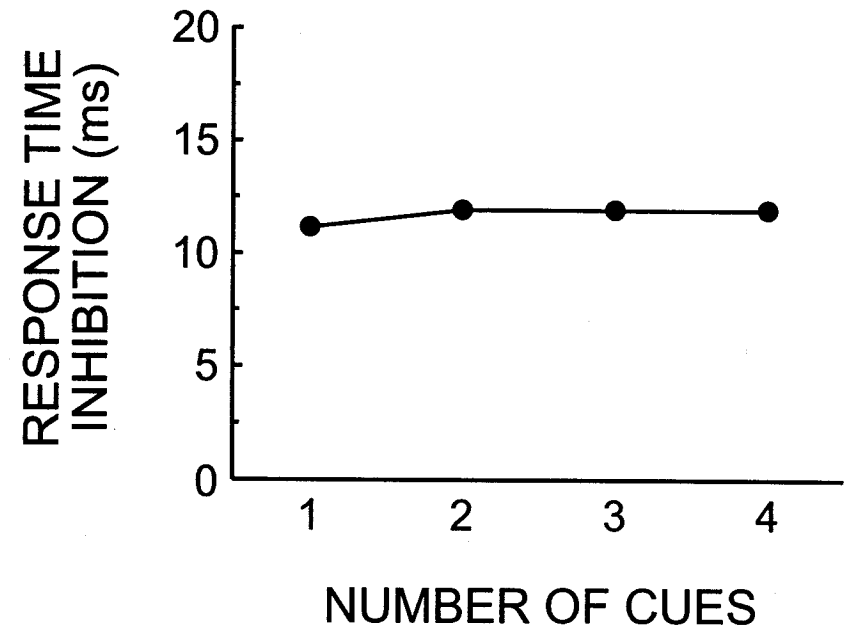

Figure 4: Mean inhibition-of-return (IOR) magnitudes for single, double, triple, and quadruple simultaneous cue presentations.

We conducted another study in which cues were presented sequentially at 100 ms intervals rather than simultaneously (Wright & Richard, 1994). The results indicated that fewer locations were inhibited at the same time following multiple sequential cue presentation than following simultaneous cue presentation. To elaborate, when four peripheral direct cues were presented in sequence before a central distractor, there was strong IOR (24 ms) at the most recently cued location, less but still significant IOR (12 ms) at the second most recently cued location, and no inhibition at the other cued locations. Interestingly, when another sequential-cue study was conducted with a longer delay between the presentation of the central distractor and the second most recently cued location (1560 ms as opposed to 400 ms in our experiment), no IOR occurred at that cued location (Pratt & Abrams, 1995). Instead, IOR occurred at only the most recently cued location. Thus, IOR produced by sequential multiple cueing appears to depend on the delay between cue onsets. When this delay is shorter, IOR may occur at two or more sequentially cued locations, but with a magnitude that decreases as the time between the cue's onset at that location and the onset of the central distractor is increased. A similar finding has since been reported (Tipper, Weaver, & Watson, 1996). We suggested that,

when multiple cues are presented sequentially, some form of serial processing is carried out at each cued location in turn that diminishes IOR magnitude at the previously inspected cue location (Wright & Richard, 1994, 1996a). And, combined with a long delay between sequential cues, this can be sufficient to diminish IOR at all but the most recently cued location.

IOR can be produced if goal-driven attention shifts are accompanied by goal-driven saccades (Posner et al., 1985) and even if subjects merely prepare to make an accompanying goal-driven saccade without actually making it (Rafal et al., 1989). Therefore, a relationship exists between IOR and eye movement programming. Some researchers have argued that IOR is the direct result of a saccadic eye movement program being inhibited. And, because of this oculomotor inhibition, a target appearing at that saccade destination will take longer to respond to (e.g., Tassinari et al., 1989). The multiple location IOR finding is inconsistent with oculomotor accounts of IOR, however, because eye movements cannot be programmed and executed to more than one location at a time. What might be simultaneously inhibited are the locations *not* to be favoured as eye movement destinations. Therefore, we argue that the relationship between eye movement programming and IOR is indirect. IOR may occur at a saccade destination because saccade preparation involves preliminary spatial indexing of that destination; and it is this indexing that occurs prior to oculomotor programming (and also as a result of abrupt stimulus onsets) that could mediate IOR.

If, as we claim, indexing mediates IOR, then IOR should conform to one of the general properties of indexes. As pointed out in other chapters (e.g., Pylyshyn, this volume; Wright & Ward, this volume), a spatial index can remain dynamically bound to an object while it moves. This leads to the following prediction. If IOR is mediated by indexing and an indexed object moves during the course of an experimental trial, then the inhibition associated with that object should move along with it. And this, in fact, is what occurs (Tipper, Driver, & Weaver, 1991). To elaborate, if the first of two successive direct cues is presented and then changes location prior to target onset as in Figure 5, IOR occurs at the cue's new location. IOR is said to *object-based* because it is dynamically bound to the moving cue just as spatial indexes remain bound to moving objects.

The discovery of object-based IOR raised questions about a continued inhibitory effect at the cue's old location after that cue was moved elsewhere. Recent studies indicate that IOR occurs at both the original and the new cue locations on the same trial (Tipper, Weaver, Jerreat, & Burak, 1994). The former is referred to as *location-based* IOR. The occur-
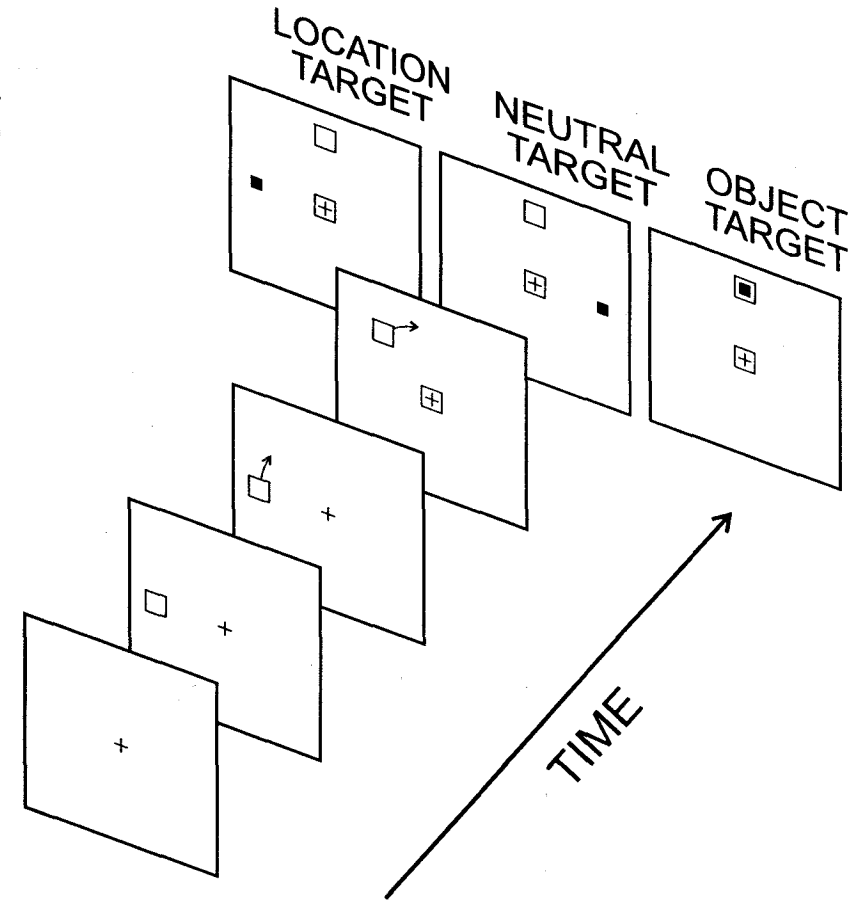

Figure 5: Typical display used for generating object-based inhibition of return (IOR).

rence of simultaneous location-based and object-based IOR is further evidence of multiple-location IOR. But, rather than presenting two cues in sequence, the same cue is simply moved from one position to another to produce IOR at both locations.

In summary, the multiple-location IOR effect is difficult to explain purely in terms of attentional processes or purely in terms of oculomotor inhibition. We suggest that IOR is mediated by a location encoding procedure called spatial indexing. In the next section, we examine data indicating that spatial indexing is the only the first stage of operations mediating IOR. Those that follow are not reflexive and may be the result of intermediate-level vision.

Automatic and Reflexive Effects of Location Cueing

Direct location cues (e.g., a bar marker or outline box) trigger saccades or attention shifts by appearing at or near a probable target location. Symbolic cues (e.g., an arrow or digit) provide information about where to voluntarily aim saccades or attention shifts. Saccades and attention shifts triggered by direct cues are under stimulus-driven control and those initiated by symbolic cues are under goal-driven control (Wright & Ward, this volume). Valid cues correctly indicate the impending target's location, and can facilitate the speed and accuracy of responses associated with that target. On the other hand, invalid cues incorrectly indicate the impending target's location, and can inhibit response speed and accuracy.

When IOR occurs, direct location cues first facilitate and then inhibit target-detection response times as the cue-target-onset-asynchrony (CTOA) is increased from 100 to 300 ms (Maylor, 1985; Maylor & Hockey, 1987; Posner & Cohen, 1984; Possamai, 1985; Wright, Richard, & McDonald, 1994; Wright & Richard, 1996b; see Figure 6). It has been suggested that when the CTOA is 100 ms or less, a facilitative component is active and dominant; and when the CTOA is 300 ms or more, an inhibitory component is active and dominant (Maylor, 1985; Posner & Cohen, 1984). This is sometimes referred to as the "biphasic" effect of location cueing. In this section, we argue that activation of the inhibitory component is not mandatory. There are some situations, for example, in which a direct cue will continue to facilitate rather than inhibit response times when the CTOA is 300 ms or more (e.g., Cheal & Lyon, 1991). Furthermore, IOR does not appear to be elicited by direct location cueing if attention is actively engaged while the cues are presented (Richard & Wright, 1995). Therefore, the time-course of direct location cue effects as a function of CTOA should be described as follows. Direct cues facilitate detection response times for targets presented within 100 ms of cue onset and, in some but not all cases, inhibit response times for targets presented 300 ms or more after cue onset.

The commonly held view that IOR occurs as a reflexive consequence of direct location cueing is consistent with Posner and Cohen's (1984) proposal that it is due to sensory rather than attentional processing. We agree that the inhibitory effects of location cueing may be automatic but, as the title of this chapter states, they are not in our opinion reflexive (cf. Tipper, Weaver, & Houghton, 1994). Instead, IOR may be due, in part, to nonreflexive processes that occur after low-level sensory operations but prior to high-level serial operations associated with alignments of attention.

Automatic and reflexive processing are both thought to be carried out independently of attention (e.g., Anderson, 1982; Kahneman &
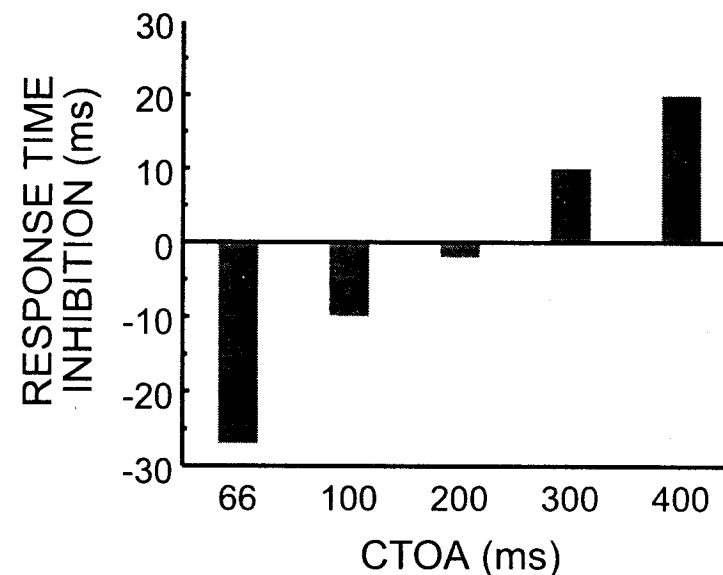

Figure 6: Time course of facilitative and inhibitory direct location cue effects on target-detection latencies as a function of CTOA (cue-target-onset-asynchrony).

Treisman, 1984; LaBerge & Samuels, 1974; Logan, 1988, 1992; Logan & Compton, this volume; Schneider, Dumais, & Shiffrin, 1984). Because of this similarity, a distinction between them is not always made. In general, automaticity develops with practice, presumably to enable skilled performance to be autonomous from attention. On the other hand, reflexive processing is mediated by low-level mechanisms that are unaffected by practice and operate independently of attention.

Visual search for a target object positioned among an array of distractor objects can be rapid and effortless in some cases, or slow and effortful in others. Usually, rapid detection or "pop out" of a target is the result of reflexive, preattentive processing; and slower detection is the result of serial attentive analysis of the visual array. In the latter case, however, visual search can become rapid if practice leads to automatization of responses to the target (e.g., Czerwinski, Lightfoot, & Shiffrin, 1992; Schneider et al., 1984; Treisman, Vieira, & Hayes, 1992). A series of experiments was carried out to determine whether or not automatized search processes are the same as (unpracticed) rapid pre-attentive search processes (Treisman et al., 1992). Automatized search was found to be more task-specific and target-location-specific than search mediated by preattentive analysis. This suggests that preattentive target popout is mediated by fundamentally lower-level processes than automatized target popout (see Figure 7).

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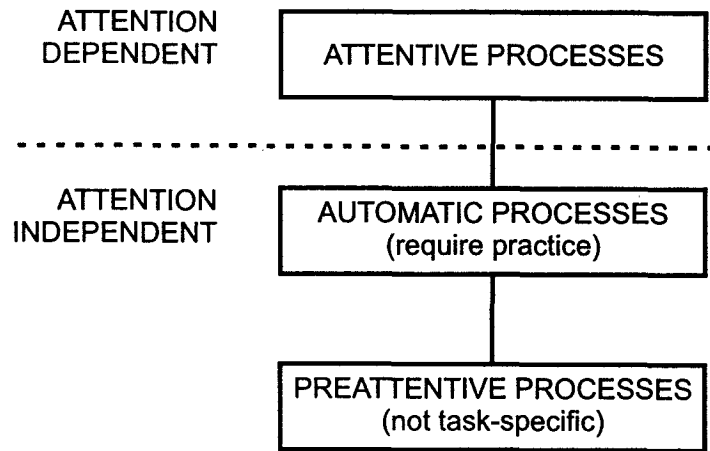
Figure 7: Attention dependent and independent processing. The latter includes automatic and reflexive operations.

Reflexive processing should not be affected by observers' expectations and cognitive strategies. For example, it should not be affected by changes in location cue validity. As observers progress through an experimental session, the usefulness of a location cue for performing the task becomes apparent to them. But if processing is reflexive, then this information should make no difference because reflexes are not strategic. As seen in Figure 3, when targets are likely to appear at cued or uncued locations with roughly equal probability, response-time facilitation usually occurs when the CTOA is 100 ms or less and inhibition can occur when the CTOA is 300 ms or more (e.g., Abrams & Dobkin, 1994; Maylor & Hockey, 1987; Posner & Cohen, 1984). We conducted a set of experiments in which cue validity was manipulated to determine how it would affect this pattern of facilitation and inhibition (Wright & Richard, 1996b; Wright, Richard, & McDonald, 1994). We found, as expected, that with both low-validity cues (10% probability that the target would appear at the cued location) and high-validity cues (90% target probability), response-time facilitation still occurred at shorter CTOAs (100 ms). On the other hand, IOR did not occur at the longer CTOAs (400 ms) with low-validity or high-validity cues. Thus, changes in cue validity affected the inhibitory but not the facilitative effects of location cueing. This suggests that the former is less reflexive than the latter.

We concluded that IOR will not occur at a direct cued location unless there is a reasonable degree of uncertainty (more than 10%) about the target appearing there. The occurrence of inhibition appears to depend on whether it will make target search more efficient. That is, given the choice, why use processing resources to inspect and keep track of a location where the target probably will not occur? IOR may depend instead on whether the perceiver needs to keep track of inspected locations in order to bias the search to other novel locations.

We were intrigued by the finding that IOR is not invoked reflexively and yet occurs rapidly and without our conscious awareness. Processes like this are often the result of automatization. Therefore, we reasoned that if IOR is an automatized phenomenon, then it should become more efficient with practice. We tested this prediction by comparing the performance of experienced observers who had participated in several IOR experiments in our laboratory with the performance of inexperienced subjects. Prior to the study, we had observed informally that experienced observers showed IOR even at quite short CTOAs. The results of the first experiment verified that with a 200 ms CTOA, experienced observers showed a significant IOR effect whereas inexperienced observers did not (Richard, Wright, & McDonald, 1994). This suggests that practice increases the efficiency of IOR by decreasing the delay required for it to occur. Practice effects on IOR have since been found in other laboratories (e.g., Tipper & Weaver, this volume).

We also asked inexperienced subjects to perform the same task but with a 100 ms CTOA. This delay was chosen because, initially, the effect of location cueing on target-detection responses was expected to be facilitative. We examined the effect of practice over the course of successive testing sessions on different days and found that the facilitation magnitude of direct cueing decreased significantly from the first block (13 ms) to the fourth (-6 ms), and this change from facilitation to inhibition across sessions showed a significant linear trend. Increases in IOR efficiency that occurred as inexperienced observers became more practiced is another indication that IOR is not a completely reflexive phenomenon and that some aspect of the processing is becoming more automatic even though the perceiver may not be consciously aware of it.

IOR magnitude appears to change not only over the course of a target detection experiment but sometimes even over successive trials. In one study, targets were sometimes presented at the same location on two or more successive trials, and response times on the second of these trials were still inhibited when a target was presented at the same location as that of the previous target (Maylor & Hockey, 1987). This inhibition decreased slightly, however, when a target was presented at the same location as the previous two targets, and continued to decrease with further increases in the number of target location repetition (see also, Posner, Cohen, Choate, Hockey, & Maylor, 1984). Maylor and Hockey (1987, p. 53) claimed that this "location-repetition effect" on IOR can be attributed to the observer's subjective expectancy

about the target's location, and speculated that, in order for IOR to occur, the locations of successive events may need to be random. Notice the consistency of their claim with our finding that IOR is more likely to occur following uninformative location cues and less likely to occur when there is a reduction in the uncertainty about the impending target's location (Wright & Richard, 1996b; Wright et al., 1994).

Unlike reflexive processes, higher-level visual processes appear to require attentional resources. This was tested with a target-detection task involving direct and symbolic location cues (Jonides, 1981). In one condition, when observers also performed a concurrent memory-load task, the response-time facilitation caused by direct cueing was virtually unaffected by the concurrent task but the facilitation caused by symbolic cueing was significantly attenuated. It was concluded that the symbolic cue task competed for attentional resources with the memory load task, but that the direct cue task did not. In other words, the facilitative effects of direct location cueing were more reflexive. When another concurrent task experiment was conducted under conditions in which direct cueing produced response-time inhibition, the magnitude of cue effectiveness decreased (Posner et al., 1984). This suggests that the inhibitory effects of direct cueing are less reflexive than the facilitative effects.

Table 1 summarizes the facilitative and inhibitory effects of direct location cueing. In general, facilitation appears to be reflexive and inhibition appears to be nonreflexive.

	Facilitation	Inhibition
CTOA (cue-target-onset-asynchrony)	Active within 200 ms of cue onset	Occurs from 300 ms to as long as 3000 ms after cue onset
Cue Validity	Little or no effect	Occurs if cues are uninformative
Practice	Little or no effect	Reduces minimum CTOA at which inhibition occurs
Location Repetition	Little or no effect	Reduces inhibition magnitude
Concurrent Tasks	Little or no effect	Reduces inhibition magnitude

Table 1: Factors that interact with the facilitative and inhibitory effects of direct-location cueing

Intermediate-Level Visual Processing

If IOR is an automatic process, why does it only occur in some cases and how do we control its initiation? Answers to these questions can be framed by a discussion of three levels of visual processing. There is a consensus among researchers studying different aspects of vision that the underlying operations occur in stages (e.g., Dawson, 1991; LaBerge, 1995; Marr, 1982; Neisser, 1967; Posner, Petersen, Fox, & Raichle, 1988; Pylyshyn, 1989; Rock, 1983; Treisman & Gormican, 1988; Ullman, 1979, 1984). One way in which processing stages have been distinguished is the extent to which they are under bottom-up control versus top-down control. Another is the extent to which parallel versus serial processing is involved. The initial stage, often referred to as low-level vision, is characterized by parallel processes that are triggered in a stimulus-driven manner (e.g., edge detection & motion correspondence matching). They are not consciously available to the perceiver and seem immediate and effortless. In contrast, high-level visual processes are usually serial and under voluntary control. The perceiver is also usually aware of their execution (e.g., when visually searching a collection of objects for a target). Between low- and high-level vision there appears to be another stage involving rapid but serial operations such as those required for determining spatial relations among objects (Ullman, 1984). Like low-level processes, they seem immediate and effortless (e.g., determining whether X is inside Y) but, like higher level processes, are under voluntary control. This stage has been called *intermediate-level visual processing* because it can be rapid and not fully available to conscious awareness without, at the same time, being purely reflexive, like low-level processing.

Processing at the intermediate level has been described in terms of *visual routines* of primitive or basic operations (Ullman, 1984). A routine is said to be "tailored" to carry out the perceptual task at hand by putting together some of these basic operations in a particular sequence. And there are some indications that spatial indexing is a basic operation (Jolicoeur, Ullman, & MacKay, 1986; Pylyshyn & Storm, 1988; Yantis, 1992). Routine assembly and execution begins with the formulation of a *computational goal* (hence the term *goal-driven*, commonly used to describe voluntary attention shifts and eye movements). The perceiver decides what task to perform, and then a specialized routine composed of basic visual operations (e.g., marking a location) is assembled and triggered. We propose that this is the level of processing at which IOR occurs.

The occurrence of IOR that is modifiable with practice may seem contradictory. We suggest that it can occur because the IOR routine involves two separate processing stages. The first is a *spatial indexing*

stage that encodes locations of stimuli. The second is an *inhibitory designation* stage that receives input about indexed locations and invokes an inhibition routine that designates certain encoded positions as low-probability target locations. If a target appears at a location with this designation, more time will be required to respond to it because it is no longer part of the high priority search set. The efficiency of the second stage can be modified with practice, perhaps because the speed of inhibitory designation becomes more streamlined with repeated execution (cf. Anderson, 1982; Ullman, 1984). To summarize, we propose that activation of the indexing stage operates in combination with an automatized inhibitory designation stage to enable IOR to be visually triggered by direct location cueing or voluntarily initiated by saccade initiation, but modifiable with learning.

Concluding Remarks

The IOR findings described in this chapter have several ramifications. Regarding the debate between Posner and Cohen (1984) and Maylor (1985) about whether or not attention must be focused at a particular location before it can be inhibited, it seems clear that Posner and Cohen (1984) were correct – attentive analysis of a location is not a necessary condition for IOR. Multiple-location IOR is indicative of parallel sensory analysis. The multiple location IOR effect also raises doubts about a purely oculomotor account of IOR because it is unlikely that multiple saccade programs can be initiated at the same time. By process of elimination, this leaves us with a mechanism that must be neither purely attentional nor purely oculomotor, and must account for the dynamic binding of IOR with objects that move from one location to another. We suggest that when IOR occurs, spatial indexes serve as location pointers that an intermediate-level routine uses to guide serial analysis by constraining the search set.

Acknowledgments

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