INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction..

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI®

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

University of Alberta

The role of inhibition of return in visual search

by

Janice Jacqueline Snyder ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of *Doctor of Philosophy*

Department of Psychology

Edmonton, Alberta

Fall 2000

National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisitions et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-59671-0

Canada

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

University of Alberta

Library Release Form

Name of Author: *Janice Jacqueline Snyder*

Title of Thesis: *Inhibition of Return and Visual Search*

Degree: *Doctor of Philosophy*

Year this Degree Granted: *2000*

Janice Jacqueline Snyder
1924 Nectarine Street
Philadelphia, Pennsylvania
19130

Date submitted:
16 August 2000

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *Inhibition of Return and Visual Search* submitted by *Janice Jacqueline Snyder* in partial fulfillment of the requirements for the degree of *Doctor of Philosophy.*

Walter F. Bischof, PhD
(Supervisor)

Alan Kingstone, PhD
(Co-supervisor)

Michael R. W. Dawson, PhD

Eugene Lechelt, PhD

Brian Maraj, PhD

Richard Abrams, PhD

August 14, 2000

Abstract

My dissertation research is aimed at understanding the attentional mechanisms that mediate visual search. More specifically, my research focuses on a phenomenon called inhibition of return (IOR) where people are slower to respond to a stimulus if it is presented in a location that was previously attended. This delay in response time (RT) is thought to reflect a bias to attend novel locations which, in turn, should serve to improve visual search efficiency. However, the question of whether IOR really plays an important role in visual search has been debated in the literature. My research addresses this question from several angles. One line of research examines whether the bias to attend novel locations reflects facilitation at unattended locations, inhibition at attended locations or both. A second line of research employs a novel paradigm to investigate the role attention has in multiple IOR and the causes of the apparent decline in IOR over multiple locations. A third line of research couples the novel paradigm for investigating multiple location IOR with more traditional visual search paradigms. And a fourth line of research examines whether multiple IOR is location-based, object-based or both.

The first section of this thesis presents the paradigms used to study attention, and IOR, in particular. The second section reviews the evidence supporting a functional role of IOR in visual search. The third section presents my own studies that demonstrate that attention is important for establishing multiple IOR, that both the addition of cued locations and decay processes are responsible for the decline in IOR across cued back locations, that IOR is of greater benefit when visual search is difficult, and that multiple location IOR is coded in spatial coordinates.

Acknowledgment

Sincere thanks to my supervisors, Walter Bischof and Alan Kingstone, for taking the time to teach me the many things that I needed to learn.

Thanks to my family, Ray, Lindsay, and Jen; my friends, Linda Allen and Meta McDonald; and the Glee Club, Corinne Zimmerman, Jacqueline Leighton, and Leanne Willson for all their support and encouragement over the last four years.

This research was supported by scholarships from the Alberta Heritage Foundation for Medical Research (AHFMR) and the Natural Sciences and Engineering Research Council of Canada (NSERC). In addition, the research reported in Chapters 1-6 was supported by grants from AHFMR and NSERC to A. Kingstone; and the research reported in Chapters 5 and 7 was supported by a grant from NSERC to W. F. Bischof.

Table of Contents

List of Figures

List of Tables

CHAPTER 1: INTRODUCTION

The human visual system is constantly inundated by rich and complex sensory information. However, most of this information is irrelevant for functioning effectively in the environment. It is clear that a detailed and continually updated representation of the environment is not needed to generate coordinated and coherent goal-directed behaviour (Allport, 1989; Rensink, O'Regan, & Clark, 1997). For instance, for a successful search of our environment, it is not necessary to have a moment-to-moment representation of every element in the visual field but rather only those elements that are relevant for the task at hand. Thus, visual search of the environment provides a good illustration of coordinating behavioural goals with action. A successful and efficient search necessarily involving a reduction of the plethora of visual information available such that only a small amount of the information registered by the visual system is processed to the level that impacts behaviour directly.

The visual system limits the selection of information in two ways. First, the visual field is spatially separated such that fine detail is available only for information located on the fovea with less detail available for information located peripherally. High resolution in the foveal region is possible because ganglion density is higher and the ganglion cell receptive fields are smaller here than in the peripheral region. Hence, resolution is lower in the periphery and progressively decreases as distance from the fovea increases (Rodieck, 1998).

Second, information is selectively processed via the control of the visual attention system. Mechanisms of selective attention operate by enhancing the processing of information that is relevant to a particular behavioural goal while filtering out or inhibiting irrelevant information (Pashler, 1998). Control over visual attention is exerted both by exogenous (bottom-up stimulus-driven) and endogenous (top-down goal-driven) processes (Jonides, 1981; Müller & Rabbitt, 1989; Yantis & Jonides, 1990), and efficient behaviour depends upon a balanced interaction between these two controlling processes. In one case, the process involves reflexive and automatic orienting with the physical properties of a stimulus object attracting attention. This exogenous orienting typically occurs when a sudden or abrupt event occurs in the environment, for example, a changing traffic light or a fast-approaching vehicle. In the other case, the process involves conscious or strategic orienting with the observer allocating attention voluntarily to a stimulus object. This endogenous orienting is the result of specific behavioural goals, for example, looking left and right before crossing a street, or moving one's eyes from one word to the next when reading.

Attention may be deployed in response to exogenous or endogenous signals in one of two ways. When an interesting object is located in the visual field, eye, head or body movements occur, (overt shifts of attention) so that the target stimulus is situated on the fovea. However, attention can also move around the visual field, independent of overt orienting. These covert shifts of attention are what is often referred to in everyday language as "looking out of the corner of one's eye."

Selective attention has frequently been investigated using visual search and attentional orienting paradigms. Visual search research has been aimed at understanding how humans are able to locate a single object in a complex and often crowded environment. The typical visual search paradigm requires observers to determine the presence or absence of a target amongst a variable number of distractors (nontargets). Targets are sometimes detected easily regardless of the number of distractors present (called parallel, popout, preattentive, feature, or efficient search); while in other cases, targets are located less easily with search difficulty increasing as the number of distractors increases (called serial, attentive, conjunction, or inefficient search). (See Figure 1 for examples of parallel and serial search and Figure 2 for typical results pattern observed in these tasks.) These studies are specifically concerned with the role played by attention in efficient target selection. Based on the results of these investigations, three models of human search behavior have been proposed.

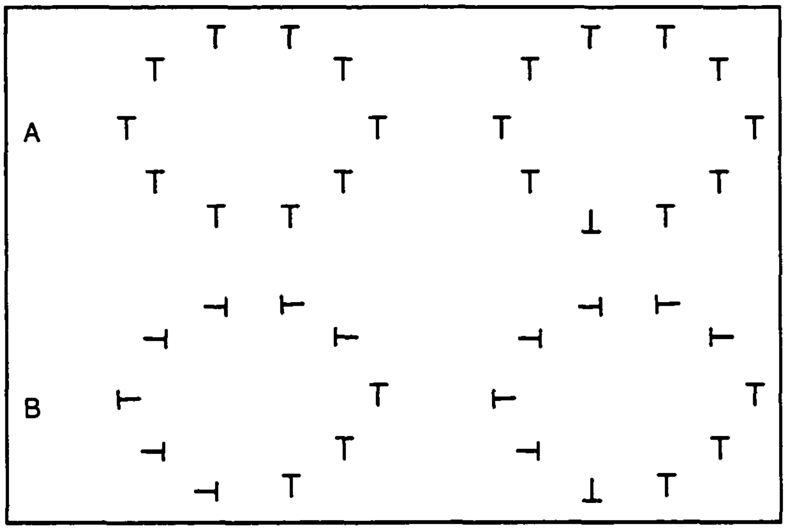

Figure 1. Examples of (A) parallel and (B) serial search displays. The presence or absence of the target (an inverted "T") is most easily detected in Panel A where the distractors are identical to each other and different from the target

The feature integration theory as originally proposed by Treisman and colleagues (Treisman, 1988; Treisman & Gelade, 1980) postulated that processing of visual information occurs in two stages. Initially, the activity of elementary features, such as color, orientation, and size, are registered in parallel and automatically in separate specialized modules or feature maps. If a target can be identified by a unique elementary feature (e.g., color), detection occurs in this first stage based simply on the presence of activity in the map for that feature. In this parallel or feature search, response time (RT) does not vary with the number of distractors. In addition to separate feature maps, a "master map of locations" is generated that specifies the location, but not the identity, of each feature present in the visual field. If a target can be identified only by a combination of features (e.g., color and form), a second slower stage of processing occurs. In this stage, separate features are located and integrated into separate object representations through the serial allocation of attention to particular locations on the master map of locations. In this serial or conjunction search, RT increases with the number of distractors. Subsequent modifications to this theory (Treisman, 1998), that are too extensive for the purpose of this review, allow for different forms of attentional selection through excitatory and inhibitory interactions between the location map, feature maps, an object file, and a later selection stage that determines the object file that should control response output.

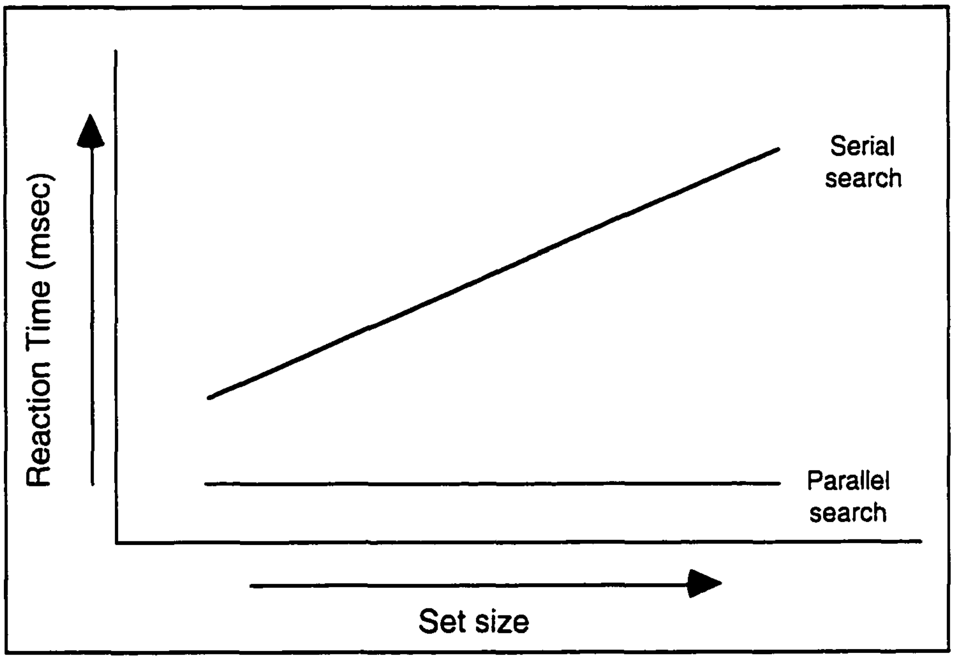

Figure 2. Typical set size effects for parallel and serial search. Set size has little effect on RT in parallel search tasks but increases monotonically with set size in serial search tasks.

The guided search theory (Wolfe, 1994; Wolfe, Cave, & Franzel, 1989) posits a first stage of massive parallel processing in which individual features are located across the visual field and objects are compared with their neighbors in terms of these basic features. In the second stage, several kinds of information are brought together in parallel to guide a subsequent checking process. In this stage, a modest number of candidate target locations are interrogated one by one to determine if they contain a target. The key difference in this theory is that the second stage is guided by the output of the first stage.

The attentional engagement theory (Duncan & Humphreys, 1992; Duncan & Humphreys, 1989) claims that there are no fundamental differences in the way parallel and serial searches are conducted. First, a highly processed parallel perceptual grouping and description of the visual array occurs, followed by a competitive interaction between the inputs. Similarity between the target and the distractors plus similarity between the distractors account for easy versus difficult search patterns. Search is more difficult when the target is similar to the distractors, and when the distractors are less similar to one another. Dissimilarity among distractors and target-distractor similarity result in less efficient search because they cannot be grouped efficiently and are eliminated from the search thorough spreading suppression.

Importantly, a common feature of all these search theories is that they acknowledge activation or inhibition as part of the target selection process. Both the feature integration and guided search theories permit selective inhibition or activation of particular feature maps while the attentional engagement theory permits inhibition through the grouping and suppression of similar nontargets.

These visual search studies have addressed some of the issues relevant to our everyday searches. For instance, the target of our search often has to be selected from among multiple distractor items that share features with the target. Both excitation of target features and inhibition of distractor features have been proposed to account for efficient location of a target item. In these studies, attention has been presumed to play a crucial role in the rapid and efficient search of the environment. Locating a target does not appear to occur in a random manner but rather through some selection process that first identifies potential targets and then chooses from amongst the candidates.

One issue not addressed in the visual search literature, though, is the need to prevent re-inspection of previously examined locations or items. This issue has, however, been addressed in the attentional orienting literature. For search to be efficient, and not random or chaotic, there has to be some way to keep track of the locations or objects that have been inspected. One way to achieve such efficiency would be to systematically mark or tag locations with inhibition as they are searched. The existence of an inhibitory mechanism that could play a role in preventing the return of attention to previously inspected locations was first demonstrated by Posner and Cohen (1984).

In this study, three outline placeholders were arranged along the horizontal axis (see Figure 3). One of the peripheral locations was cued briefly (i.e., brightened) to draw attention to that location. Target probability was manipulated to induce the withdrawal of attention from the peripheral cue and return it to fixation. Critically, the cue was uninformative with the target appearing equally often in the two peripheral locations. Observers were instructed to keep their eyes fixated on the central placeholder and to respond to the target with a keypress as quickly as possible.

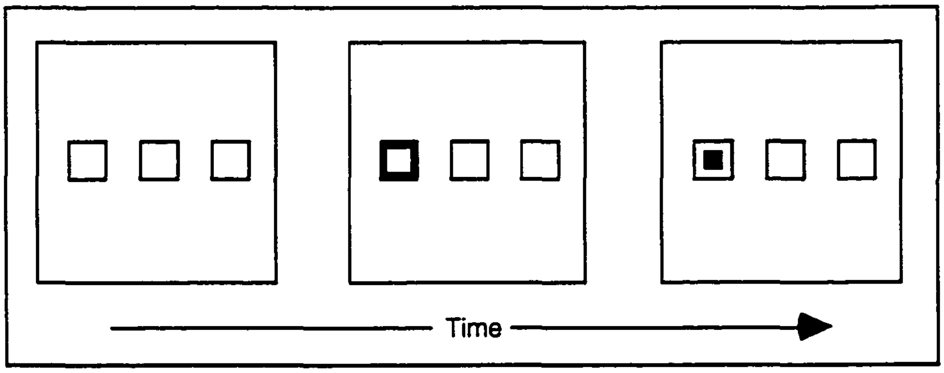

Figure 3. Procedure used by Posner and Cohen (1984, Experiment 1): the center placeholder is fixated; one of the peripheral placeholders is cued (brightened) for 150 ms; following a delay of 0, 50, 100, 200, 300, or 500 ms a target appears on 80% of the trials. Target probability is 0.6 at the center location and 0.1 at each of the peripheral locations. In this example, the target occurs at the cued location.

One of two effects was observed at the cued location depending on the time delay between the onset of the peripheral cue and the onset of the target. As illustrated in Figure 4, one effect when cue-target latencies (stimulus onset asynchronies or SOAs) were less than 150 milliseconds (msec), was a shorter RT for a target at a cued location than at an uncued location. This facilitatory effect has been demonstrated in numerous studies (e.g., Jonides, 1981; Klein, Kingstone, & Pontefract, 1992; Müller & Rabbitt,

1989) and is believed to represent speeded perceptual processing at the cued location. However, when cue-target latencies were longer than 300 msec, the facilitatory effect was replaced by an inhibitory effect. That is, now RT was longer at a cued than at an uncued location.

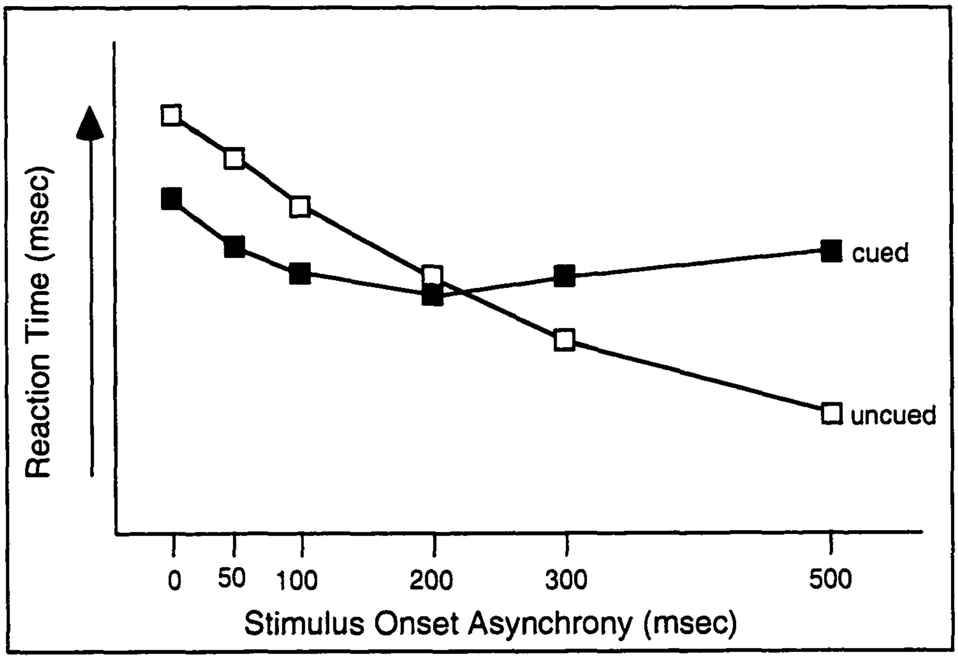

Figure 4. Typical RTs in a cuing paradigm. When the cue onset precedes target onset at a SOA of less than 150 ms, RT is shorter at the cued location. When the SOA is 300 ms or greater, RT is longer at the cued location.

This inhibitory effect was replicated using the brightening of the fixation stimulus, rather than a probability manipulation, to induce the removal of attention from the cued locations, and with four rather than two peripheral locations, indicating that this effect was not an artifact of motion perception or strategic responding. The inhibitory effect was subsequently named inhibition of return (IOR) (Posner, Rafal, Choate, & Vaughan, 1985) reflecting the hypothesis that attention was inhibited from returning to a previously examined location. Posner and Cohen (1984) suggested that the functional importance of IOR was to facilitate visual search of the environment by integrating attention and eye movements thereby creating a bias for novel locations and objects. This bias, they argued, occurred automatically without deliberate intention on the part of the observer.

The notion of IOR functioning as a facilitator of search is intuitively appealing. Therefore, it is not surprising that many studies have been conducted to determine whether IOR plays an important in our ability to efficiently search our environment. However, conflicting findings regarding the role of IOR in search have emerged. In the next chapter, this literature will be reviewed.

CHAPTER 2: INHIBITION OF RETURN AND VISUAL SEARCH

The previous chapter described Posner and Cohen's (1984) study which showed that IOR can be obtained (a) by brightening the central fixation to remove attention from a cued location and (b) when four rather than two peripheral locations are in the display. Posner and Cohen further, they also showed that responses were delayed for a target presented at a previously stimulated environmental but not at a previously stimulated retinal location, thus demonstrating that IOR is coded in environmental rather than retinotopic coordinates (see also Maylor, 1985). Since much of our orienting behavior involves eye and/or head movements, this finding that inhibition remains at the attended location despite changes in retinal location is critical for the assumption that IOR plays any role search.

Another crucial piece of supporting evidence for a functional interpretation of IOR was provided by Posner and Cohen's (1984) examination of the duration of the IOR effect. They reported that when a single location was cued, IOR was observed for at least 1.5 seconds. This finding is important because several (e.g., four to six) eye movements to novel locations could occur during this time frame.

In most of our searches, our eyes move to explore complex visual scenes where there are numerous nontargets, many of which resemble and compete with the target. This scenario contrasts sharply with the search in Posner and Cohen's (1984) study, where the target was a single luminance increment occurring in a sparse environment of identical nontarget items. If IOR plays a general role in visual orienting behavior, then it must represent a general bias against a recently attended location and it should not be limited to responses based only on simple target detection. For this reason, IOR has been studied in more general situations such as in saccadic tasks, in discrimination tasks, in dynamic scenes, and at multiple locations in search displays.

Inhibition of Return in Saccadic Tasks

If IOR functions to facilitate search then it should have a close relationship to eye movements since searching the environment is accomplished through both covert and overt attentional shifts. One requirement, then, would be that in addition to finding a slowing of manual RT at a previously fixated location as reported by Posner and Cohen (1984) and other investigators (Maylor, 1985; Rafal, Calabresi, Brennan, & Sciolto, 1989) IOR should also be observed for saccadic RT to a previously fixated location. A number of studies have shown direct support for this hypothesis. For instance, (Vaughan, 1984) found longer saccadic RT to a target at and around a previously fixated location relative to a new location when observers fixated sequentially a series of targets. Likewise, other investigators found that when observers covertly attended an abrupt stimulus onset/luminance increment in the periphery, saccadic RT to that location was slower (Abrams & Dobkin, 1994b; Posner et al., 1985; Reuter-Lorenz, Jha, & Rosenquist, 1996) Furthermore, it was also found that when two peripheral targets were presented on either side of fixation, observers had a definite bias to make a saccade to the location that had not been previously peripherally cued (Posner et al., 1985). A similar finding has also been reported with infants (Clohessy, Posner, Rothbart, & Vecera, 1991).

In a comprehensive examination of the relationship between overt and covert orienting, Rafal et al. (1989) measured response latencies to a peripheral target following either a covert or an overt shift of attention. In that study, RT was longer when a saccade was directed to a cued rather than an uncued location (i.e., the IOR effect). This finding held whether observers shifted their attention (a) covertly to a luminance increment at a peripheral location, (b) overtly by making a saccade to a peripheral location cued by a central arrow, or (c) overtly by making a saccade to a luminance increment at a peripheral location.

More recently, Klein and MacInnes (1999) presented participants with a complex visual scene taken from the "Where's Waldo?™" book series. Participants were encouraged to make saccades in an effort to find "Waldo". After a number of saccades, a probe item was presented and participants were required to foveate the probe. The placement of the probe was determined using the coordinates from the participants' current and previous fixation positions. In this manner, Klein and MacInnes found IOR as a relative increase in saccadic RT when the probe was located near a recently fixated position. They also noted that voluntary saccades made prior to probe presentation saccades were directed away from previously fixated regions, a bias that could reflect IOR.

In summary then, both manual and saccadic RT are slower for a target appearing in a previously fixated location and the direction of subsequent saccades is biased toward locations that have not been attended previously. These results are consistent with the idea that IOR plays an important role in efficient visual search. However, if IOR operates as a general attention mechanism that facilitates search, then the effect should emerge not only in detection tasks but also in more complex situations, for instance, when target discrimination is required.

Inhibition of Return in Discrimination Tasks

Detecting the sudden onset of a single target in a nearly empty display hardly constitutes a search. Therefore, finding evidence of IOR in a discrimination task is imperative if IOR is to be regarded as mechanism promoting efficient search. The generality of IOR was challenged by several investigators who failed to observe IOR in discrimination tasks where target localization was not required for the response. For instance, neither Terry, Valdes, and Neill (1994) nor Egly, Rafal, Henik, and Berger (under review) found evidence of IOR for shape discrimination using the same paradigms that generated IOR for a detection responses. Kwak and Egeth (1992) observed IOR when target localization was required but not when the task involved discriminating color or orientation. Similarly, Tanaka and Shimojo (1996) did not find IOR for discrimination of color, orientation, size discrimination, vernier, or luminance. In addition, Kingstone and Gazzaniga (1992, reported in Klein & Taylor, 1994) also failed to find IOR in a color discrimination task and Pontefract and Klein (1988, reported in Klein & Taylor, 1994) failed to find evidence of IOR in a size discrimination task.

Other investigations have, however, firmly established that IOR can be found in discrimination tasks involving both eye movements and manual responses. Pratt (1995) found evidence of IOR when observers were required to discriminate a target from a nontarget and make a saccadic eye movement to the target. Using a similar procedure, Pratt and colleagues (Kingstone & Pratt, 1999; Pratt & Abrams, 1999; Pratt, Kingstone, & Khoe, 1997) observed robust IOR in a manual discrimination task (see also Cheal, Chastain, & Lyon, 1998 and Danziger, Kingstone, & Snyder, 1998). It is clear that IOR can occur for discrimination tasks so why does IOR occur in some discrimination tasks but not in others?

In an effort to resolve this inconsistency, Lupiáñez, Milan, Tornay, Madrid, and Tudela (1997) noted that some failures to obtain IOR could have resulted from using a target-target paradigm. Therefore, they used different cue-target intervals to explore the robustness of IOR in detection and color discrimination tasks. They found IOR operating in both tasks but noticed that the time course for IOR was different for discrimination than for detection tasks. That is, IOR appears in discrimination tasks if an adequate interval between cue and target onset occurs but its onset is delayed. They also noted that several of the studies failing to demonstrate an IOR used a continuous response (i.e., a target-target) paradigm. This finding is important because as Klein (2000) notes, it may be possible that the IOR effect is obscured as the result of a response-repetition effect that is particularly salient in target-target paradigms.

In a second study investigating the time course of IOR, Lupiáñez and Milliken (1999) extended their investigation to determine the underlying differences and time course of IOR for detection and discrimination tasks. They suggested that at the start of a trial, and importantly prior to the onset of the cue, observers set the level of attention that will be used for a task. For a relatively easy task, such as simple detection, a low attentional setting will be effected whereas for a more attentionally-demanding task, such as a discrimination task, a high attentional setting will be effected. When the cue occurs, the same attentional setting set for the target will apply to the cue, even though it is not voluntarily attended. Thus, when the response task requires discrimination, attention will be allocated to the cued location for a longer period of time to allow for the increased processing and/or response selection requirements. Such an increase in attentional allocation at a cued location results in a delayed IOR effect. In addition, Lupiáñez et al. (1999) found a differential effect when a distractor stimulus was presented in the location opposite of the target. When a target appears in isolation (i.e., without an accompanying distractor), the attentional control setting to locate a target onset will also apply to a cue onset. In this situation, attention remains at a cued location for a longer time and consequently delays the onset of IOR. When a target appears with a distractor, a different attentional control setting (i.e., one that does not involve onsets) is necessary to locate a target and thus attention will not be captured as strongly by a cue onset. In this case, IOR will appear sooner. Furthermore, in situations where a target is accompanied by a distractor on some of the trials, the appearance of IOR will rest on the probability of whether a distractor will co-occur with a target. Taken together, these findings have provided considerable explanatory power to account for previous failures to find IOR in discrimination tasks.

Based on early failures to provide evidence of IOR in more complex search tasks, the generality of IOR was questioned. However, it is now generally agreed that IOR does occur for discrimination tasks as well as for target detection and localization tasks. Thus far, the studies described involved tasks where IOR was generated at a specific location in the visual field. Although location-based IOR is useful when searching for static objects, it would not be useful in situations requiring interactions with mobile objects.

Object-based Inhibition of Return

Tipper, Driver, and Weaver (1991) argued that in searches involving interactions with moving objects, attention should interact with objects, such that avoiding the return of attention to previously inspected objects would require an object-based IOR. This conjecture has gained support from the finding that attentional mechanisms can operate on objects rather than space (Duncan, 1984; Egly, Driver, & Rafal, 1994). To investigate whether IOR occurred for objects as well as locations, Tipper and colleagues (Tipper, et al., 1991; Tipper & Weaver, 1998; Tipper, Weaver, Jerreat, & Burak, 1994) conducted experiments aimed at establishing the existence of object-based IOR. They used an IOR paradigm where, following a peripheral cue, the placeholders were rotated so that a cued object could occupy an uncued location and a cued location could now contain an uncued object (see Figure 5). Evidence of IOR was found for the cued location as well as for the cued object relative to uncued locations/objects in the display.

Several other experiments support the conclusions of Tipper and colleagues by demonstrating that IOR effects are not solely determined by inhibition of locations. Abrams and Dobkin (1994b) showed that when a previously examined object moves, inhibition moves with the object when a manual but not when a saccadic response is required (but see Klein, 2000 for an alternative account). Gibson and Egeth (1994) also found evidence of object-based IOR in a study aimed at investigating whether IOR could accrue to positions within an object. More recently, object-based IOR effects have been observed by Ro and Rafal (1999).

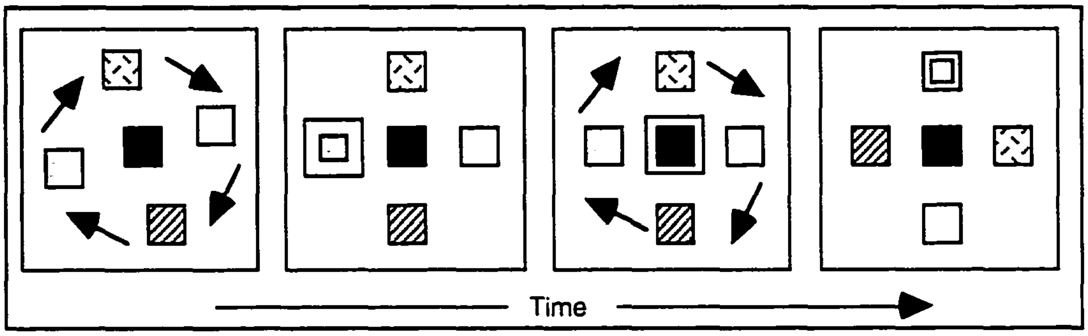

Figure 5. Procedure used by Tipper, Weaver, Jerreat, and Burak (1994, Experiment 4). At the start of a trial, the peripheral squares are rotated around the central fixation square. The motion stops and one of the peripheral squares is cued. Following a brief delay, the central square is cued and movement resumes for 90°. In this example, the target occurred at the cued object/uncued location.

Contrary to these observations, Müller and von Mühlenen (1996) failed to obtain object-based IOR effects, although they found evidence of location-based IOR. However, Weaver, Lupiáñez, and Watson (1998) provided evidence that Müller and von Mühlenen's (1996) failure to generate object-based resulted from a reduction of IOR due to extensive practice in that study.

Overall, there is a considerable amount of evidence suggesting that IOR can accrue to objects and to locations. At present, the findings that IOR occurs for saccadic as well as manual responses, in more complex discrimination tasks, and be generated for objects as well as locations are all in accord with the hypothesis that IOR functions to facilitate search. Several other areas of investigation have provided further support for the role of IOR in search. These investigations have included testing for the underlying neural substrate of IOR.

Neural Mechanisms Mediating Inhibition of Return

Several investigations by Rafal and colleagues (Danziger, Fendrich, & Rafal, 1997; Posner et al., 1985; Rafal et al., 1989) have shown that oculomotor programming, rather than covert orienting, is related to the generation of IOR. Indeed, Posner and Cohen (1984) provided the first evidence that covert orienting may not be sufficient for producing IOR. They found that although IOR occurred in response to an exogenous cue (i.e., an abrupt onset in the periphery) drawing attention to the peripheral location, it did not occur in response to an endogenous cue (i.e., a predictive arrow presented at fixation) directing attention to a peripheral location (also see Rafal et al., 1989, Experiment 4).

In an investigation aimed at elucidating the neural mechanism underlying IOR, Posner et al. (1985) compared performance in patients with lesions to the midbrain that either did or did not involve the SC and in patients with cortical lesions. The patients of primary interest were those with progressive supranuclear palsy (PSP) which involves severe degenerative of the midbrain including the SC and is characterized by an impairment in making vertical saccades and orienting attention in the vertical direction. The horizontal plane is usually affected only late in the time course of the disease. IOR effects were compared in the horizontal and vertical planes. The PSP patients but not the other patient populations showed an impairment in obtaining an IOR effect. Further, they produced an IOR effect in the horizontal plane but not in the vertical plane.

Rafal et al. (1989) also demonstrated the importance of oculomotor behavior in generating IOR. In one experiment with normal observers, IOR was found using endogenous cues when an eye movement was either prepared or executed. In a second experiment, exogenous cues presented in the temporal hemifield under monocular viewing conditions resulted in more IOR than cues presented in the nasal hemifield. Visual input to the SC is asymmetrically represented such that most of the visual information comes from the temporal hemifield (Rafal, Henik, & Smith, 1991). Finding a greater magnitude of IOR in the temporal hemifield is, therefore, consistent with the SC mediating IOR.

In a study that combined the gap effect, a phenomenon resulting from the disinhibition of oculomotor programming in the SC, and IOR, Abrams and Dobkin (1994a) found that the gap effect was smaller for saccades to a target presented at a previously attended versus an unattended location. This result provides an important link to IOR and the SC. Further support for the role of the SC in generating IOR comes from the finding that IOR occurs in infancy (Clohessy et al., 1991; Hood, Atkinson, & Braddick, 1998; Valenza, Simion, & Umiltá, 1994). Since cortical development is not completed in infants, the retinotectal pathway must be generating IOR.

Tipper et al. (1994) suggested that location-based and object-based IOR are mediated by separate neural substrates. They argued that it is unlikely that subcortical structures mediate object-based IOR since neurons in the SC do not encode speed and direction of motion efficiently. They suggested that cortical systems mediate object-based IOR. Tipper et al. (1997) found support for this idea in two "split-brain" patients with complete lesions of the corpus callosum (thus severing the link between the cortical hemispheres). They hypothesized that if object-based IOR is mediated by the SC, then IOR should move with the object but if it is mediated by cortical structures, then it should move with the object as long as that object stays in the same visual field. Results showed object-based IOR when the cued object moved within the same visual field but not when it moved to the opposite visual field.

Danziger et al. (1997) studied two patients with hemianopia to determine whether the midbrain was sufficient for generating IOR. These patients had suffered a unilateral lesion to the primary visual (striate) cortex and as a result were completely blind in the entire contralesional hemifield. Partial support for the role of the oculomotor system in the generation of IOR was found for one of the patients who showed IOR in both the unaffected or seeing field and the blind field. However, the second patient did not show IOR in the blind field.

Elaborating on Tipper et al.'s (1997) finding that object-based IOR requires intact cortical structures for the coding of IOR in object-based coordinates, Danziger et al. (1997) further suggested that although IOR may be generated by the retinotectal pathway, IOR may not be involved in the maintenance of the spatiotopic representation. It is possible, they argued, that the inhibitory tag generated by the SC may be fed up to the parietal cortex via the pulvinar for spatiotopic coordinate coding.

More recently, Sapir, Soroker, Berger, and Henik (1999) have found direct evidence of collicular involvement in IOR. In a patient with a unilateral lesion to the dorsal midbrain that included the SC, IOR was obtained in the hemifield projecting to the intact SC but IOR was not obtained in the hemifield projecting to the lesioned SC. This finding allowed for the conclusion that IOR is generated by the SC.

Although these studies provide converging evidence that the SC is necessary to generate IOR, it may not be sufficient for the observation of IOR. Recent work by Dorris and colleagues (Dorris, Everling, Klein, & Munoz, 1998; Dorris, Taylor, Klein, & Munoz, 1999) showed that neuronal activity in the SC is greatly reduced when a target appeared in a cued versus an uncued location and clearly demonstrates that the SC reflects IOR. However, when examining the pre-target background (build-up) activity of the neurons, they discovered higher levels of activity for a cued than for an uncued locations. This finding suggests that neurons in the SC are not directly inhibited but rather that indirect inputs are received form other brain systems, possibly the parietal cortex, representing the cued locations.

In summary, there is a considerable evidence suggesting that the SC mediates the generation of IOR. Converging evidence that the SC is involved in generating IOR comes from studies demonstrating (a) a lack of IOR in patients with degenerative midbrain disorder involving the SC (PSP), (b) temporal-nasal hemifield asymmetries in normal observers, (c) an interaction with the SC-mediated gap effect, (d) IOR in infants, (e) the IOR effect in a hemianopic patient's blind field, and (f) unilateral IOR generation in a patient with a midbrain lesion. And although preliminary evidence supports the idea that location-based and object-based IOR are mediated by different neural substrates and that the SC may not be directly inhibited in IOR but may receive reduced input from other brain regions, further investigations are necessary.

Having established that the generation of IOR occurs in the SC, what type of effect does it have? This issue has been debated in the literature with conflicting opinions that IOR represents either motor or attentional processing.

Motor Bias Versus Attentional Effect

Posner et al.'s (1985) proposal that it is attention that is inhibited from returning to the cued location has not gone unchallenged. Klein and Taylor (1994) proposed that it is not attention that is inhibited but rather it is a bias against making a motor response to a previously attended location. This reasoning followed from the finding that IOR was only observed for tasks that required target localization (e.g., Pontefract & Klein, 1988, reported in Klein & Taylor, 1994; Tanaka & Shimojo, 1996; Terry et al., 1994). Taylor and Klein (1998) further argued that the evidence of IOR biasing saccadic direction (Posner et al., 1985) in addition to slowing saccadic responses (Abrams & Dobkin, 1994b; Maylor, 1985; Posner & Cohen, 1984) also supports the motor bias account of IOR. Furthermore, the absence of an IOR effect in temporal order judgments (Maylor, 1985; Posner & Cohen, 1984) and in illusory line motion (Schmidt, 1996) provide indirect support for the motor bias account. Because attentional involvement is assumed to be reflected by perceptual slowing, the finding that IOR does not affect perceptual processing supports the notion that IOR is not attentional.

However, Reuter-Lorenz et al. (1996) took a different approach and suggested that if IOR were an attentional effect, then factors that affect the magnitude of attentional costs and benefits, such as target modality and target intensity, should similarly affect IOR. In this study, a visual or auditory target occurred equiprobably on either side of fixation following a visual cue on either side of fixation. Results indicated that IOR was greater for visual than for auditory targets; that for both visual and auditory targets, target intensity influenced IOR; that for both visual and auditory targets, IOR of equal magnitude was found for manual and saccadic responses. These results are consistent with the pattern of results observed for attentional orienting.

Although covert attentional orienting does not appear to be sufficient for generating IOR, it does not imply that attention does not play a role in IOR. Indeed, Rafal et al. (1989) suggested that IOR appears to bias covert attentional orienting. In addition, most of the concerns raised by Klein and Taylor (1994) to discount an attentional account of IOR have been resolved. For instance, as noted previously, IOR has been reliably demonstrated in discrimination tasks that do not require a target localization component. These results have been augmented by Handy, Jha, and Mangun (1999) who have recently demonstrated that IOR affects accuracy of target discrimination, thus providing direct evidence that IOR can affect perceptual processing. Evidence of an oculomotor and an attentional component of IOR has been reported by Kingstone and Pratt (1999). They found larger IOR effects when saccades were executed than when manual responses were executed, suggesting that in addition to an attentional component, a motor component contributes to the IOR effect. Further compelling evidence that IOR results from attentional modulation comes from an event-related brain potential study conducted by

McDonald, Ward, and Kiehl (1999). Using an IOR orientation discrimination task, they found that long cue-target intervals elicited a larger P1 effect, which is taken to be reflective of the attentional modulation of early perceptual processing.

Thus, it appears that IOR may be composed of a motor component and an attentional component.

Facilitatory Effect Versus Inhibitory Effect

The studies discussed so far imply that IOR creates a bias to commit attention to locations that have not been attended by inhibiting attention from returning to a previously attended location. This line of reasoning has led investigators to consider that IOR might serve to facilitate search of the environment both by discouraging attention from reinspecting previously examined locations and by encouraging attention to inspect unexamined locations. The studies cited thus far have produced strong empirical support for the idea that IOR discourages attention from revisiting previously searched locations or objects (see for example Klein, 1988; Klein, 2000; Müller & von Mühlenen, in press; but see Horowitz & Wolfe, 1998 for an alternative view).

There is, however, little evidence that IOR actually facilitates the direction of attention to unattended locations. For example, in their seminal paper on IOR, Posner and Cohen (1984; Experiment 2) investigated whether facilitatory processes could be operating at any specific uncued locations. No particular facilitatory effects were observed.

Recently, however, a study by Pratt, Spalek, and Bradshaw (1999) has provided preliminary evidence that in addition to the inhibition observed at the cued location, a facilitatory effect can be observed at the uncued location opposite of the cued location (see also Tassinari, Biscaldi, Marzi, and Berlucchi, 1989). Pratt et al. attributed this facilitatory effect to a phenomenon that they call "attentional momentum". According to

Pratt et al., when attention is removed from a cued peripheral location and directed to the central fixation location an "attentional momentum" is created such that there is a bias away from the cued peripheral location and toward the opposite uncued peripheral location.

Consider, for instance, the situation in which centered around fixation there are peripheral placeholders placed at twelve, three, six and nine o'clock. On a given trial the twelve o'clock placeholder is brightened drawing attention to that location, and then central fixation is brightened which draws attention to the center of the display. According to the momentum hypothesis this shift in attention from the top placeholder to the center of the display creates a bias for attention to continue moving in the direction in which it most recently traveled, that is, to the opposite uncued six o'clock location.

Importantly, the direction of this attentional momentum can be changed when a target occurs, but it takes time, with greater changes requiring more time. Thus, in the above example, RT would be shortest when a target appeared at the uncued six o'clock location (no change in the path of momentum), RT would be longer but equivalent for a target at the uncued three or nine o'clock location (90° change in the path of momentum), and RT would be longest for a target at the originally cued twelve o'clock location (180° change in the path of momentum producing the classic IOR effect). Pratt et al. tested this idea in a series of five experiments. Based on their findings they suggested that attentional momentum underlies the IOR effect.

It is important to note that these results are preliminary evidence in support of the idea that IOR operates primarily by facilitating the movement of attention to unattended locations. Therefore, this hypothesis warrants further investigation. The issue of whether IOR can occur at more than one location in a search has also been debated in the literature. This concern is important because if IOR functions to facilitate efficient visual search, then more than one location would have to be inhibited in a search.

Inhibition of Return at Multiple Locations

Most IOR research uses paradigms where one of two possible locations is cued. If IOR facilitates visual search then it must be sustained concurrently at several previously attended locations. Posner and Cohen (1984) and Maylor (1985) reported the presence of IOR at two locations when both locations were cued simultaneously. But arguably the first comprehensive test of IOR at multiple locations was conducted by Klein (1988). This experiment also constituted the first direct test of the role of IOR in visual search. Klein reasoned that if IOR was important for search, evidence of IOR should be found for attentionally-demanding or serial search but not for nonattentionally-demanding or parallel search. To test this idea, he presented observers with serial and parallel search tasks (Treisman and Gelade, 1980), and on some trials the search task was followed by speeded luminance detection of a probe stimulus. The probe could occur at a location previously occupied by a display item or at a previously empty location. As predicted by Klein's hypothesis. observers were slower to detect the luminance probe when it occurred at a location previously occupied by an item in the display only when observers had performed a serial (i.e., an attentional) search. This study yielded the first empirical evidence that IOR could be an important mediator of efficient visual search. Unfortunately, subsequent attempts to replicate Klein's results failed (Klein & Taylor, 1994; Wolfe & Pokorny, 1990) although more recent investigations have replicated Klein's original finding (e.g., Müller & von Mühlenen, in press; Takeda & Yagi, in press).

The above studies are consistent with the notion that IOR can be generated by visual search tasks. Unfortunately, in such search tasks, it is impossible to know where an observer's attention has been or when it was allocated on any given trial. Hence. the presence of IOR can only be inferred and its efficacy in facilitating visual search is speculative.

In order to obtain an explicit measure of IOR at multiple locations, Pratt and Abrams (1995) cued two locations in succession (either one at each of the peripheral locations or two at the same location). They found that IOR occurred only at the most recently cued location.

This conclusion was challenged by Tipper, Weaver, and Watson (1996) who cued three out of four locations successively and found robust IOR at each of the cued locations. In a reply to Tipper et al., Abrams and Pratt (1996) suggested that cuing three of the four locations may have encouraged grouping of the cued locations in a single area of inhibition. They repeated the Tipper et al. (1996) experiment, increasing the number of possible target locations from four to six and always cuing three nonadjacent locations. Results indicated that IOR occurred only at the most recently cued location.

In summary, a large number of empirical studies attest to the robustness and generality of the IOR effect. Several findings support the view that IOR is a suitable mechanism for facilitating efficient search of the environment. These findings include that IOR can be found for saccadic as well as for manual responses, in situations more complex than simple detection tasks, and that it has an object-based representation. However, one serious challenge to the efficient search hypothesis remains. Although IOR can occur for a single diffuse region of space, it has not yet been demonstrated to occur at more than one nonadjacent location. Finding conclusive evidence that multiple location IOR can occur will be critical for confirming its role as a search facilitator.

There is much evidence to support the view that IOR affects both the return of attention and motor responses. Converging evidence comes from the finding that IOR can occur for discrimination tasks, that it can affect perceptual processing, that factors affecting attentional costs and benefits similarly affect IOR, and that saccades are biased to unattended locations in the absence of a peripheral target.

Research outcomes from many laboratories have demonstrated that IOR is a candidate mechanism involved in visual search of the environment. In a variety of studies, it has been shown that IOR is coded in environmental coordinates, that it is a long-lasting effect, that it can be found for more difficult task demands, that it has an object-based representation, but that it cannot occur at multiple noncontiguous locations. The finding that IOR results from the programming of a saccade is consistent with the manner in which the environment is searched (i.e., with eye movements). And finally, the finding that IOR appears to have an attentional as well as a motor component is important because it suggests that IOR would be responsive to and under the control of the observer. Taken together, these results suggest that further investigations of IOR as a facilitator of efficient visual search are warranted.

Overview of Thesis Work

Although the studies detailed above have answered many questions concerning the nature of IOR, it is not known whether IOR (a) is primarily an inhibitory or a facilitatory effect and (b) can occur at multiple nonadjacent locations. These questions are addressed in this thesis.

It is clear that the first question that must be addressed is whether the role of IOR is one of facilitation at one or more new locations or inhibition at one or more old locations. Although finding supporting evidence that IOR operates by a facilitation process does not challenge the role of IOR in search, it will be critical for designing subsequent investigations of IOR.

If IOR plays a role in efficient search, then it should occur at multiple locations. Therefore, one area of investigation must be aimed at elucidating the factors that might encourage the generation of IOR at multiple locations. If multiple location IOR is obtained, then the boundary conditions under which multiple IOR will be found must be elucidated.

CHAPTER 3: INHIBITION OF RETURN: FACILITATION OR INHIBITION?

In the previous chapter, one of the questions raised was whether IOR results from inhibitory or facilitatory processes. If, in fact, a facilitatory effect is the primary component underlying IOR, it is (a) necessary to confirm that finding and (b) establish the boundary conditions under which this facilitatory effect operates. The first experiment was designed to replicate and expand upon Pratt et al.'s (1999, Experiment 1) finding that when attention is moved along a path, it has a tendency to continue moving in that direction (i.e., an attentional momentum). Specifically, if a peripheral cue is presented, followed by a central fixation cue, attentional momentum moves along a path from the cued peripheral location to center and results in a facilitatory effect at the uncued location opposite to the cued location.

In Experiment 1, the temporal relation between the peripheral cue and the central fixation cue was manipulated in an effort to modulate attentional shifts from the cued peripheral location back to center. Surprisingly, although a robust IOR effect was observed, no momentum effect was found. In Experiment 2, the possibility was explored that the manipulation used in Experiment 1 may have contaminated the momentum effect. In this experiment, though a momentum effect was found, it was a much weaker effect than IOR, it did not occur for all cue-target directions, and it was found for only a few observers. Experiment 3 was a final attempt to determine whether the attentional momentum effect reported by Pratt et al. was the same effect observed in the present Experiment 2. The results of this experiment confirmed the finding that an inhibitory effect, not a facilitatory effect, underlies IOR.

Experiment 1

If a shift in attention from a peripheral location to center generates a momentum effect, then interfering with that shift should interfere with the momentum effect. In Experiment 1, the modulation of attentional shifts from the periphery to central fixation was achieved by varying the duration of the peripheral cue. There were three critical conditions. The duration of the peripheral cue could be timed to: (a) be brief enough so that its offset preceded the onset of the fixation cue (as in Pratt et al., 1999), (b) offset simultaneously with the onset of the fixation cue, or (c) overlap with and exceed the duration of the fixation cue. The hypothesis of the present experiment was that attention would be engaged at the cued peripheral location while the peripheral cue was present and/or that the ability of a central cue to attract attention would be reduced if it overlapped with the duration of a peripheral cue. Therefore, based on the findings of Pratt et al., it was expected that the attentional momentum effect, and thus IOR, would be most readily observed when the offset of the peripheral cue either preceded or coincided with the onset of the fixation cue. In other words, the momentum effect, and IOR, should have been attenuated or abolished when the peripheral cue overlapped with and exceeded the duration of the central fixation cue.

Method

Participants

Fourteen undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Apparatus and Stimuli

Stimuli were presented on a 40 cm VGA monitor controlled by a Pentium 100 computer. The stimulus display consisted of a black background with four dark gray outline placeholders located above, below, to the right and to the left of a fifth outline placeholder centered on fixation. The placeholders measured 1.5° of visual angle on each side. The center of each peripheral placeholder was 6.5° from the center of the fixation placeholder. Cuing of peripheral locations and the fixation stimulus was accomplished by superimposing a light-gray outline placeholder over a dark-gray outline placeholder. The target was a light-gray asterisk measuring 0.6° in diameter. Response latencies accurate to within 1 msec were recorded by the computer. Figure 6 (Panel A) illustrates a typical trial, with a cue duration of either 100, 250, or 500 msec, where the target appeared at the uncued location opposite the cued location. A diagram of the timing used in this experiment is included at the bottom of the figure (Panel B).

Procedure

Participants were seated in a dimly lit room, 57 cm from the display screen. They were informed that the peripheral cue was not predictive of target location (i.e., that the target was equally likely to occur at any of the four peripheral locations). Participants were instructed to maintain fixation on the central fixation placeholder throughout the trial and to respond by pressing the space bar as quickly and accurately as possible when the target appeared. Each trial began with a 100 msec warning tone. Following a 500 msec delay from the onset of the warning signal, one of the peripheral placeholders was cued. Cue durations were 100, 250, 500, 750, and 1000 msec. At 500 msec SOA from cue onset, the fixation placeholder was cued for 200 msec. The target appeared at a 1000 msec SOA timed from the onset of the peripheral cue. On catch trials, no target was presented. The intertrial interval was 1000 msec.

Design

Ten practice trials were followed by 15 blocks of 40 test trials. Participants were requested to take a break between blocks of trials. Of the 600 trials, there were 120 trials for each of the five cue durations (100, 250, 500, 750, 1000 msec). For each cue duration there were 30 cues at each of the four peripheral locations. Of these 30 trials, 25 were target trials and five were catch trials where no target appeared. Cue durations, cue locations, and target locations were each selected randomly. A single session lasted 45 minutes. All trials were terminated upon execution of a response or 1500 msec after the target onset, whichever came first. A 200 msec error tone, which was easily distinguished from the warning tone, provided error feedback when participants either anticipated a target or failed to respond to a target.

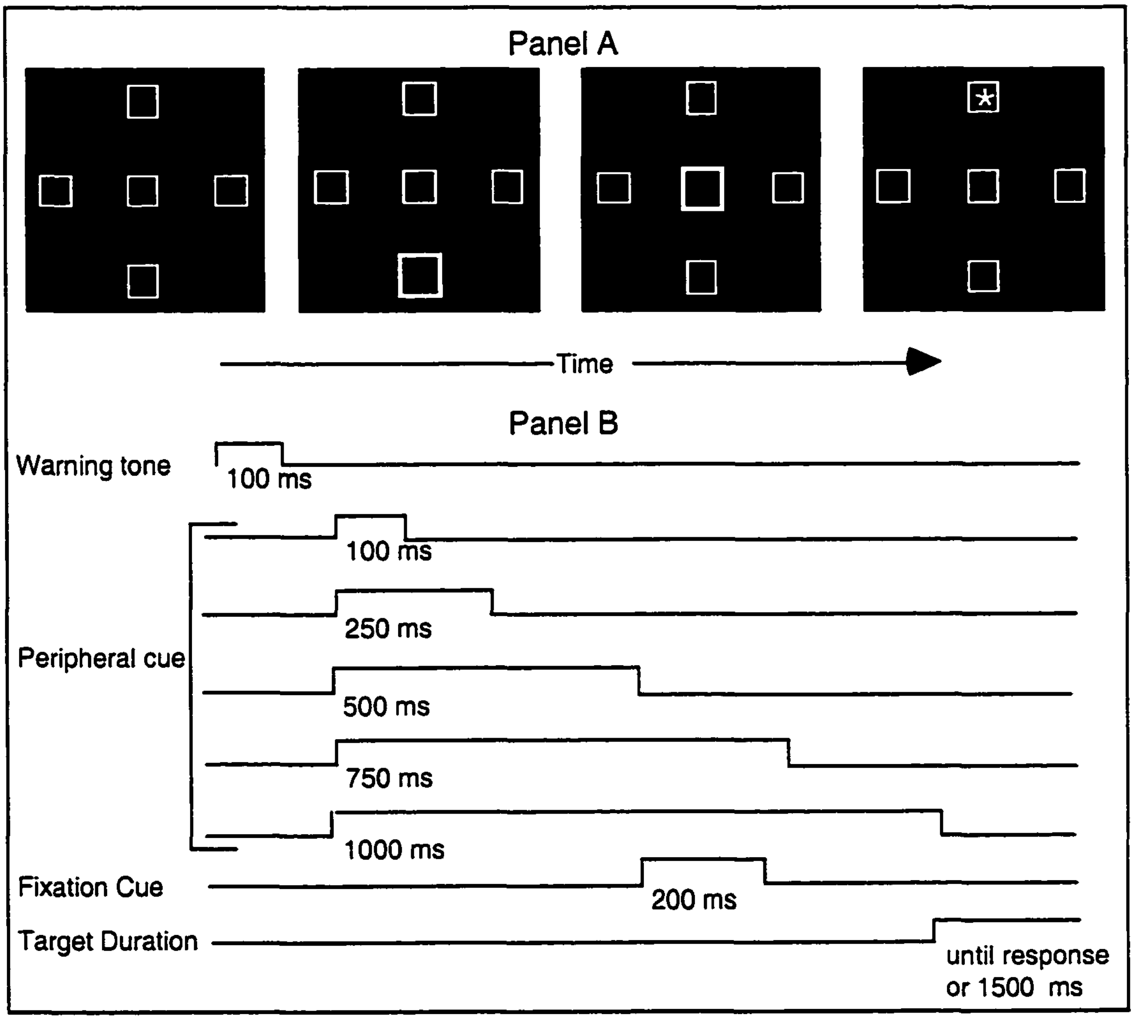

Figure 6. Panel A: the sequence of events on a trial in Experiment 1. The cue-target SOA was fixed at 1000 msec. Cue durations varied randomly and were either 100, 250, 500, 750, or 1000 msec. In this example, the target occurred at the uncued opposite location. Panel B: the timing sequence for trials in Experiment 1.

Results

Target locations are defined by their relationship to the cue. Thus, on any given trial, a target could appear (a) at the same location as the cue (i.e., cued trial), (b) at the location situated to the left of the cue (i.e., uncued left trial), (c) at the location situated to the right of the cue (i.e., uncued right trial), or (d) at the location situated opposite the cue (i.e., uncued opposite trial).

A two-factor repeated measures analysis of variance (ANOVA) with target location (cued, uncued left, uncued right, uncued opposite) and cue duration (100, 250, 500, 750, 1000 msec) as factors was conducted. Mean correct RT as a function of target location and cue duration is shown in Figure 7.

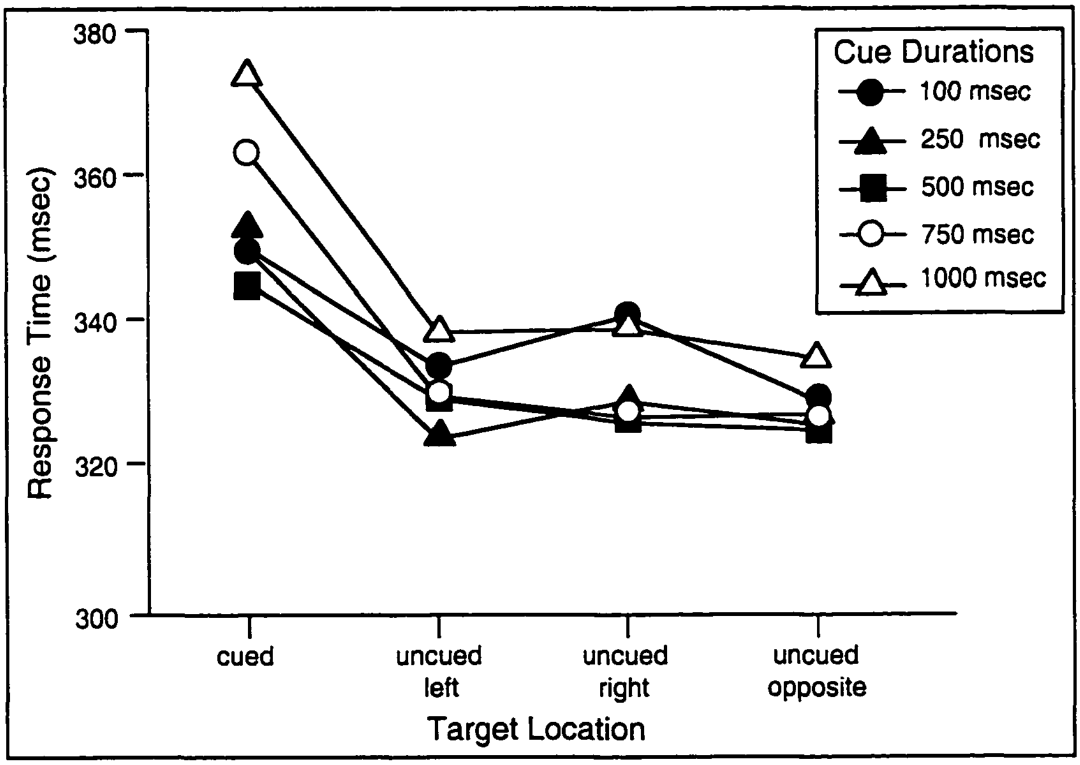

Figure 7. Mean correct RT for Experiment 1 as a function of target location (cued, uncued left, uncued right, uncued opposite).

The analysis revealed a significant main effect for target location, *F*(3, 39) = 42.28, *MSe* = 283.94, *p* < .001. A planned contrast[1] of RT to a target at a cued location (351 msec) versus RT at an uncued location (325 msec) verified that this main effect reflected, in part, IOR (cued RT longer than uncued RT), *F*(1,39) = 124.79, *MSe* = 283.94, *p* < .001. Inspection of the data revealed that contrary to the attentional momentum hypothesis, RT to a target at an opposite uncued location (323 msec) was not significantly shorter, *F*(1,39) = 1.86, *MSe* = 283.94, *p* > .1, than an RT to a target at a left or right uncued location (326 msec).

The main effect of cue duration was significant, *F*(4,52) = 8.98, *MSe* = 234.76, *p* < .001, reflecting the fact that RT at the longest cue duration was significantly longer than at any of the other shorter cue durations (341 msec RT vs. 326-333 msec RTs), all *F*s > 8.12, all *p*s < .01.

Most importantly, the target location x cue duration interaction was significant, *F*(12,156) = 2.10, *MSe* = 196.42, *p* < .05. The attentional momentum hypothesis predicts that RT to a target opposite a cued location should be shorter than RT to a target at another cued location (i.e., an "attentional momentum" effect) for at least the 100 and 250 msec cue durations but not necessarily for the 500, 750, and 1000 msec cue durations. A planned contrast comparing RT at an opposite location to an uncued left or right location across the 100 and 250 msec intervals revealed no significant differences, *F*(1, 156) = 1.95, *MSe* = 196.42, *p* > .1. Significantly, however, robust IOR was found at these same intervals, *F*(1, 156) = 40.70, *MSe* = 196.42, *p* < .001. An inspection of the cell means suggested that the interaction effect resulted from a greater magnitude of IOR for the 750 and 1000 msec cue duration trials (36 and 37 msec, respectively) than for the

---

[1] The method of Bonferroni correction for controlling Type I error in families of contrasts (see Myers & Well, 1991) was adopted for each set of contrasts performed throughout this paper. The family-wise ∂ level adopted was always 0.05 evenly divided among the number of comparisons executed in examining a given effect.

100, 250, and 500 msec cue duration trials (15, 24, and 19 msec, respectively). A post-hoc comparison pitting RT at all target locations for the 100, 250, and 500 msec durations against the RT for the 750 and 1000 msec durations confirmed this observation, $F(1,156) = 20.46$, $MSe = 196.42$, $p < .001$. Further post-hoc comparisons of uncued left and right versus opposite target RT at each level of cue duration (100, 250, 500, 750, 1000 msec) revealed that a momentum effect did not occur for any of the cue durations examined (all Fs < 3.33, all ps > .05). In contrast, a similar set of comparisons for IOR (cued versus mean uncued RT) revealed an IOR effect at each level of cue duration (all Fs > 12.57, all ps < .001).

In an effort to determine whether a momentum effect was present but obscured, individual participant data were analysed collapsing over the 100 and 250 msec durations. No significant RT differences were found when the uncued left and right locations were compared to the uncued opposite locations (i.e., RT was not shorter for an uncued opposite location) for any of the participants (0%, all Fs < 2.84, all ps > .09). On the other hand, statistically reliable IOR effects were observed for eight participants (57%), all Fs > 5.71, all ps < .02) at these same cue durations. (Eleven participants (79%) demonstrated IOR when collapsing across all cue durations.)

Thus, while IOR was robust and reliable across all cue durations -- and even greater at the two longest cue durations where the momentum effect was expected to be weakest -- there was no evidence of a momentum effect at any cue duration.

Response accuracy

Overall mean error rates were low in this experiment (0.62%). Errors were either false alarms (i.e., a response prior to target onset), anticipations (i.e., a response less than 100 msec after target onset), or missed responses (no response within 1500 msec of target onset). False alarms accounted for the majority of errors (0.48%), with fewer errors occurring as the result of anticipations (0.11%), and missed responses (0.04%). Error data were analysed with a two-factor repeated measures ANOVA with trial type (cued, uncued left, uncued right, uncued opposite, no target - catch trials) and cue duration (100, 250, 500, 750, 1000 msec) as factors. There was a significant main effect of trial type (cued, uncued left, uncued right, uncued opposite, no target), $F(4,52) = 4.73$, $MSe = 0.003$, $p < .01$. Inspection of the means suggested more errors occurred on catch trials (1.9%) than on target trials (0.9%, 0.7%, 0.3% and 0.6% for the cued, uncued left, uncued right and uncued opposite locations, respectively). A post-hoc comparison of target trials (cued, uncued left, uncued right, uncued opposite) versus catch trials supported this observation, $F(1,52) = 16.00$, $p < .001$. The lack of a significant main effect for cue duration, $F(4,52) = 1.34$, $MSe = .003$, $p > .2$, indicated that error rates did not vary between the various cue durations. Thus, the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

To summarize, the attentional momentum hypothesis was explored by varying the duration of the peripheral cue, effectively altering its relationship to the centrally located fixation stimulus. According to the momentum hypothesis, when the fixation cue occurred after the offset of the peripheral cue, an analog movement of attention should have proceeded from the cued location to fixation (Pratt et al. 1999). The uncued opposite location would then be along the path of attention, and the shortest RT would be expected at that uncued opposite location in comparison to any other location in the display. When the peripheral cue outlasted the fixation cue, it is unclear whether attention would persist at the cued location, or whether the path of attention would reverse back toward the cued location or simply be disrupted. In any case, a facilitatory effect at the opposite uncued location, and an IOR effect at the cued location, were not strongly predicted.

Surprisingly, this experiment failed to reveal any evidence of the momentum effect for any cue duration. That is, even when the analyses were restricted to cue durations similar those found in Pratt et al.'s (1999) Experiment 1, no facilitatory effect was observed. Moreover, the IOR effect was found to be strongest at the cue durations expected to produce the weakest IOR effect by virtue of disrupting an attentional shift (i.e., when the duration of the peripheral cue exceed the duration of the central cue). Indeed, in all cases a robust IOR was present, and a momentum effect was absent, even when the data were considered on a participant by participant basis.

The absence of facilitation at the uncued opposite location is an unexpected result. It is difficult to imagine that altering the relationship between the peripheral cue and the fixation cue would have such a profound effect on attentional momentum that the effect would be eliminated at all cue durations. Thus, the first test of attentional momentum suggests that the momentum effect may not be particularly robust. This is peculiar because if, as suggested by Pratt et al. (1999), the attentional momentum effect is the main component contributing to the IOR effect, one would expect the momentum effect to be large and relatively stable; especially when a large and stable IOR effect is produced as was the case in Experiment 1.

Experiment 2

Experiment 1 found a strong and reliable IOR effect across all cue durations but no momentum effect for any of the cue durations. This suggests that the attentional momentum effect may not be robust, reliable, or an important component to the IOR effect.

It could be argued, however, that the unpredictable relationship between brightening the peripheral cue and brightening the central fixation stimulus in Experiment 1 for some reason disrupted the momentum effect. While this position does not provide any obvious explanation as to why a robust IOR effect was observed in Experiment 1 in the absence of a momentum effect, this issue was addressed in Experiment 2 simply by abolishing any brightening of the central fixation stimulus.

It is well known that an IOR effect can occur even when central fixation is not brightened after a peripheral cue (Danziger & Kingstone, 1999; Maylor & Hockey. 1985) a fact that can be explained easily by the attentional momentum hypothesis. It need only be assumed that following a peripheral cue attention is returned back towards the center of the display (a reasonable 'strategy' given that a target is typically equally likely at all peripheral locations). This return to center by attention would effectively establish a path of attentional momentum away from the peripherally cued location and towards the opposite uncued location. Note that this is the same path of attentional momentum proposed by Pratt et al. (1999) when central fixation is brightened. It is also worth noting that there is some empirical support for this proposal as Tassinari. Biscaldi. Marzi. and Berlucchi (1989) have reported that an inhibitory effect at the cued location and a facilitatory effect opposite the cued location may co-occur when a central fixation stimulus is not brightened.

Experiment 2 was a replication of Experiment 1 with the exception that central fixation cuing was eliminated. This procedural change was intended to control for the possibility that the cue duration manipulation in Experiment 1 disrupted the momentum effect, and to examine whether the attentional momentum effect generalizes to IOR paradigms when fixation is not brightened after a peripheral cue.

Method

Participants

Fourteen undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli and procedure were identical to Experiment 1 except that the fixation stimulus was not cued.

Results

Data analyses were conducted as in Experiment 1. Mean correct RT as a function of target location and cue duration is shown in Figure 8. A significant main effect for target location was observed, F(3, 39) = 28.13, MSe = 567.25, p < .001. A planned contrast of RT to a target at a cued location (412 msec) versus RT to a target at an uncued location (384 msec) confirmed the presence of an IOR effect, F (1,39) = 73.18, MSe = 567.25, p < .001. A second planned contrast of RT to a target at an opposite uncued location (377 msec) versus RT to a target at a left or right uncued location (387 msec) revealed an attentional momentum effect, F = 7.89, MSe = 567.25, p < .01.

As in Experiment 1, a significant main effect was observed for cue duration, F(4, 52) = 5.58, MSe = 820.93, p < .001. No significant interaction between target location and cue duration occurred, F(12, 156) = 1.31, MSe = 395.07, p > .2, suggesting that cue duration had no effect on the magnitude of the attentional momentum effect.

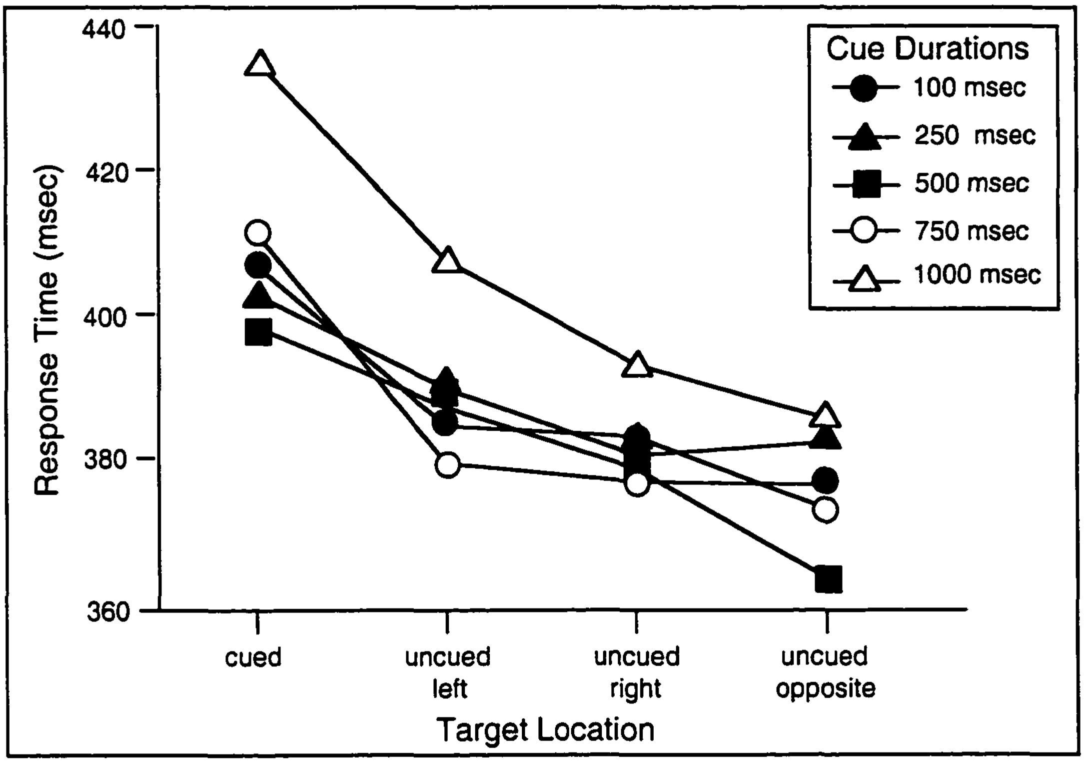

Figure 8. Mean correct RT for Experiment 2 as a function of target location (cued, uncued left, uncued right, uncued opposite).

Response accuracy

As in Experiment 1, overall mean error rates were low (0.98%) with false alarms (0.68%) accounting for the majority of the errors, with fewer errors occurring as the result of anticipations (0.12%), and missed responses (0.18%). Error data were analysed as in Experiment 1. A significant main effect was found for cue duration, F(4, 52) = 3.86, MSe = .0003, p < .01. Inspection of the means suggested more errors occurred on 750 and 100 msec (1.3% and 1.4% respectively) than on 100, 250, and 500 msec (0.5%, 1.0%, and 0.7% respectively) cue duration trials. A post-hoc comparison of the longer (750 and 1000 msec) versus the shorter (100, 250, and 500 msec) cue duration trials supported this observation, F(1,52) = 12.38, p < .001. No other main effect or interactions was observed (all Fs < 1.10, all ps > .3). Thus, the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

To summarize, an IOR effect was observed for all cue durations in Experiment 2, replicating the results of Experiment 1. And unlike Experiment 1, performance was facilitated at the uncued location opposite to the cued location. As noted previously, this pattern of results agrees both with the attentional momentum hypothesis (Pratt et al. 1999) and with the work by Tassinari et al. (1989). It also suggests that the failure to observe a momentum effect in Experiment 1 may have been due to the unpredictable relationship between the brightening of the peripheral cue and the brightening of the central fixation stimulus in Experiment 1.

But does the momentum effect obtained in Experiment 2 contribute significantly to the IOR effect as proposed by Pratt et al. (1999)? As a first pass, an examination of the individual participant data across all cue durations was conducted to determine whether the momentum effect is as robust as the IOR effect. The analysis revealed that although 11 of the 14 participants demonstrated a reliable IOR effect (79%, all $\underline{F}$s > 8.44, all $\underline{p}$s < .01), only two participants (14%) demonstrated a reliable momentum effect (both $\underline{F}$s > 10.21, both $\underline{p}$s < .01).

The data were examined further to ensure that the momentum effect (i.e., shortest RT opposite the cued location) occurred for each location in the paradigm. A two-factor repeated measures ANOVA with cue location (upper, left, lower, right location position) and target location (cued, uncued left, uncued right, uncued opposite) as factors was conducted. As in the initial analysis, a significant main effect for target location was present, $\underline{F}(3, 39) = 28.80$, $\underline{MSe} = 472.75$, $\underline{p} < .001$. But the main effect for cue location was not significant, $\underline{F} < 1$.

Of particular interest, however, was the finding of a significant cue location x target location interaction, $\underline{F}(9, 117) = 5.82$, $\underline{MSe} = 318.77$, $p < .001$. Planned contrasts examining each opposite location (i.e., when the upper, right, lower, and left positions were cued) revealed a significant momentum effect only when the upper position was cued and the target appeared at the lower position, $F(1,117) = 14.53$, $MSe = 318.77$, $p < .001$. When left, lower, or right positions were cued, no momentum effect was observed (all other Fs < 2.43, all other ps $> .1$). The IOR effect, however, was not similarly constrained as evidenced by its presence regardless of which of the four locations was cued (all Fs > 16.29, all ps $< .001$). This analysis demonstrates that in Experiment 2, the significant main effect of momentum resulted from shorter RT when only one of the four locations was cued.

A re-analysis of Pratt et al.'s (1999) Experiment 1 data with cue location and target location as factors in a repeated measures ANOVA revealed a similar position-dependent pattern of responding in their participants.[2] There was a significant main effect for target location, $F(3, 33) = 21.55$, $MSe = 1139.42$, $p < .001$. Planned contrasts confirmed the presence of IOR, $F(1, 33) = 59.72$, $MSe = 1139.42$, $p < .001$, and a momentum effect, $F(1, 33) = 4.72$, $MSe = 1139.42$, $p < .05$.[3] Neither the main effect of cue location, $F(3, 33) = 0.48$, $MSe = 465.78$, $p > .6$, nor the target location x cue location interaction, $F(9, 99) = .80$, $MSe = 598.03$, $p > .6$, was significant. Planned contrasts examining each opposite location revealed that a marginally significant momentum effect occurred only when the left position was cued and the target appeared at the right position, $F(1,99) = 6.16$, $MSe = 598.03$, $p < .02$. All other cue-target directions failed to

---

[2] The statistics reported here are based on unfiltered RTs from Pratt et al. (1999). The statistics reported in the original paper removed RTs greater than 600 msec in addition to a forced trial termination at 1000 msec. A similar pattern of results emerges regardless of filtering, though IOR is of a slightly larger magnitude and a momentum effect of slightly smaller magnitude, when post-experiment filtering is not undertaken.

[3] If Bonferroni corrections are applied to the current data to control for family-wise error, then there is no significant momentum effect, and consequently no cue-target direction effect. Note that Pratt et al. (1999) performed four independent comparisons on the data suggesting that to control for family wise error a probability level below 0.0125 would have been required to reject the hypothesis that RTs at opposite and adjacent locations were equivalent at $\partial=.05$. The probability level obtained was $p = .037$. Even when the data were filtered (see note 2) the probability level obtained was .028, suggesting that there is a greater than 5% chance that the results observed were due to chance.

demonstrate a significant momentum effect (upper position: F(1,99) < 1, right position: F(1,99) < 1, lower position: F(1,99) = 3.93, all ps > .05). Hence, as with the present Experiment 2 data, the significant main "momentum" effect in Pratt et al.'s (1999) Experiment 1 was not the product of a general orienting effect.

Finally, analyses of individual participant data revealed that while only three of the 12 participants (25%) in the Pratt et al. (1999, Experiment 1) study demonstrated a significant momentum effect (all Fs > 6.03, all ps < .05), nine of the 12 participants (75%) demonstrated IOR (all Fs > 7.44, all ps < .01).

Thus, although Experiment 2 produced a momentum effect, a detailed analysis of the data, and of the data of Pratt et al. (1999, Experiment 1) raises several problems for an attentional momentum account of the IOR effect. First, the momentum effect occurred only for a small subset of all the possible cue-target momentum directions in the present study as well as in Pratt et al. (Experiment 1), whereas the IOR effect was robust across all cue-target directions. Second, the momentum effect occurred only for a small subset of the participants in the present study as well as in Pratt et al., whereas the IOR effect was robust across the vast majority of participants. Third, the magnitude of the momentum effect grossly underestimated the magnitude of the IOR effect. And finally, a robust IOR effect can be observed without observing any momentum effect in any direction in any of the participants. This suggests that the IOR effect and the momentum effect may be independent phenomena with the former robust and reliable and the latter weak and unreliable.

Before concluding that an attentional momentum effect does not underlie IOR, it is necessary to confirm that the momentum effect observed in Experiment 2 was the same as the attentional momentum effect reported by Pratt et al. (1999). This was done by replicating Pratt et al.'s Experiment 2. The aim of that experiment was to determine whether an attentional momentum hypothesis or a spreading inhibition hypothesis best accounted for their finding that RT was shortest at the uncued opposite location. The placeholders were placed at unequal distances from the central fixation stimulus, with all peripheral locations being equidistant from each other except for the upper left and lower right locations (see Figure 9). The spreading inhibition proposal predicted that uncued locations that were equally distant from the cued location should yield equivalent RT. Results did not support this prediction and the spreading inhibition account was rejected.

Nevertheless, the paradigm used in that experiment produced an attentional momentum effect and is different from the paradigm used in the present Experiments 1 and 2. In Experiment 3, this paradigm was used as a final test to ascertain whether the momentum effect observed in Experiment 2 is in fact the same as reported by Pratt et al.

Experiment 3

Although the momentum effect observed in Experiment 2 appears to be the same as the attentional momentum effect reported by Pratt et al. (1999) confirmation of this assumption is necessary. Therefore, a replication of Pratt et al.'s Experiment 2 was conducted. Pratt et al.'s Experiment 2 was designed as a test of an attentional momentum versus a spreading inhibition account of the facilitatory effect. The critical manipulation here was that the potential cue-target locations were not equidistant from the central fixation stimulus. Rather, two cue-target placeholders were located on one diagonal (each 7.4° from fixation) while the other two were located on the opposite diagonal (each 4.3° from fixation). In the present experiment, Pratt et al.'s Experiment 2 was replicated, with the exception that central fixation was not brightened.

Method

Participants

Fourteen undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Apparatus, Stimuli, and Procedure

Stimuli were presented on a 32 cm color monitor controlled by a Macintosh PPC computer. Stimuli were as described in Experiment 1, except now the four locations were not arranged equidistantly from fixation and the fixation stimulus when present was a 0.5° cross. As in Experiment 2 of Pratt et al., two of the placeholders were arranged along a diagonal with each placeholder 7.4° from fixation (long cue-target distance). The other two placeholders were arranged along the other diagonal with each 4.3° from fixation (short cue-target distance; see Figure 9).

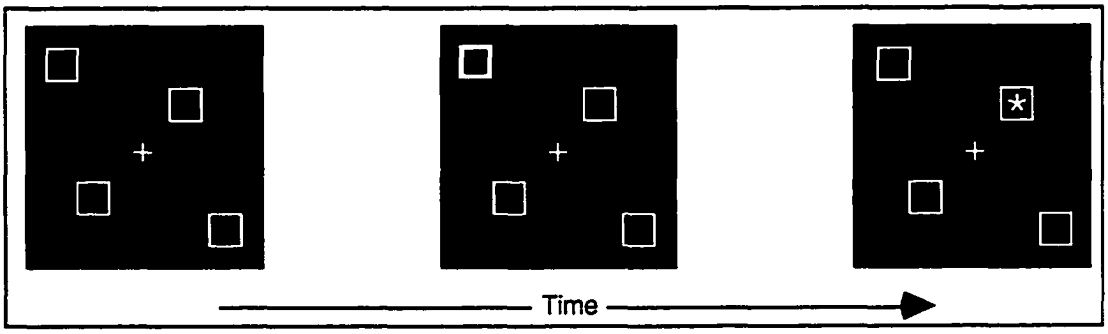

Figure 9. The sequence of events on a trial in Experiment 3. All cue durations were 250 msec. All cue-target SOAs were 1000 msec. In this example, the target appeared at the uncued right location. Upper left and lower right positions were 7.4° from fixation and lower left and upper right positions were 4.3° from fixation.

Trials began as in the previous experiments with a 100 msec warning tone. Following a 500 msec delay from the onset of the warning signal, one of the peripheral placeholders was cued for 250 msec. At 1000 msec SOA, the target appeared equally likely at any of the four locations. Intertrial interval was 1000 msec. In the fixation-present paradigm, participants were instructed to maintain fixation on the cross. In the fixation-absent paradigm, participants were instructed to maintain gaze on the center area where a fixation stimulus would be situated if there were one.

Design

The two fixation paradigms were run on the same day to explore whether the presence of the fixation stimulus played any role in the momentum effect, with order of paradigm presentation counterbalanced across participants. In each of the fixation paradigms (present, absent), 10 practice trials preceded each of the 320 test trials presented in 10 blocks of 32 trials each. Participants were requested to take a break between blocks of trials. Of the 320 test trials, upper right and lower left (i.e., a short cue-target distance) and upper left and lower right (i.e., a long cue-target distance) placeholders were cued equally often. For each of the four locations cued, the target was presented 16 times each at a cued, uncued opposite, uncued left, and uncued right location. There were 16 catch trials on which the target did not appear. The single session lasted 45 minutes.

As in the earlier experiments, all trials were terminated upon execution of a response or 1500 msec after the target onset. A 200 msec error tone provided error feedback when participants either anticipated a target or failed to respond to a target.

Results

Having found no significant main effect or interactions (all Fs < 1.30, all ps > .2) involving the fixation paradigm factor (present, absent), the data were collapsed across that factor. A two-factor repeated measures ANOVA with target location (cued, uncued left, uncued right, uncued opposite) and cue location (upper left, upper right, lower right, lower left positions) as factors was conducted. Mean correct RT as a function of target location and cue location is presented in Figure 10.

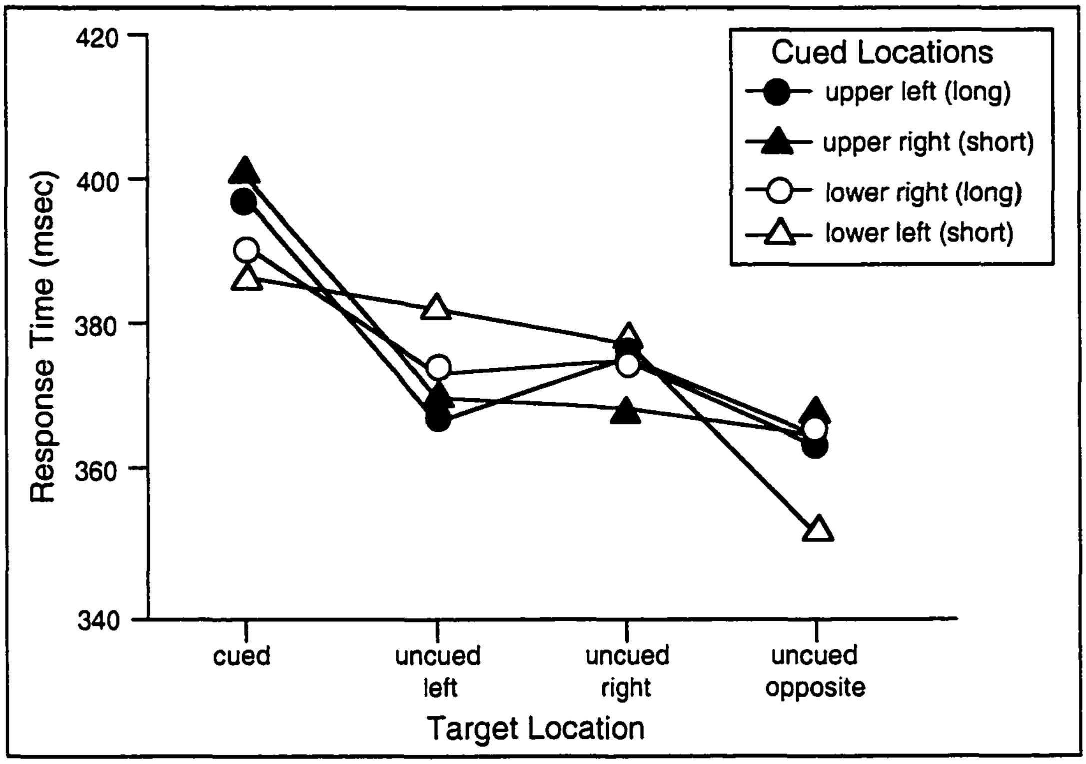

Figure 10. Mean correct RT as a function of target location (cued, uncued left, uncued right, uncued opposite) and cue position (upper left, upper right, lower right, and lower left). The upper left and lower right cue locations have long cue-target distances and the upper right and lower left cue locations have short cue-target distances.

The main effect of target location was significant, $\underline{F}(3, 39) = 18.34$, $\underline{MSe} = 573.07$ $\underline{p} < .001$. Planned contrasts revealed an IOR effect, $\underline{F}(1, 39) = 44.31$, $\underline{MSe} = 573.07$, $\underline{p} < .001$, and the presence of a momentum effect, $\underline{F}(1, 39) = 10.65$, $\underline{MSe} = 573.07$, $\underline{p} < .01$. The main effect of cue location was not significant, $F<1$.

Importantly, the target location x cue location interaction was significant, $\underline{F}(9, 117) = 2.09$, $\underline{MSe} = 312.70$, $\underline{p} < .05$. Planned contrasts revealed that although IOR was present regardless of cue location (all $\underline{F}$s > 9.26, all $\underline{p}$s < .01), a momentum effect was present only when the lower left position was cued (i.e., a short cue-target distance), $\underline{F}(1,$

39) = 25.15, MSe = 312.70, $p < .001$. No other momentum effect approached significance, all other Fs < 3.62, all other ps > .05.

Finally, analyses of individual participant data revealed that while eight of the 14 participants (57%) demonstrated reliable IOR (all Fs > 7.95, all ps < .01), only two of the 14 (14%) demonstrated a reliable momentum effect, both Fs > 5.37, both ps < .03.

Response accuracy

As in the previous experiments, overall mean error rates were low (1.5%) with false alarms (1.3%) accounting for the majority of the errors, with fewer errors occurring as the result of anticipations and missed responses (0.1% each). Error data were analysed in a two-factor repeated measures ANOVA with trial type (cued, uncued left, uncued right, uncued opposite, no target - catch trials) and cue location (upper left, lower right, upper right, lower left positions) as factors. No main effects or interactions were observed (all Fs < 1.66, all ps > .08). Thus, the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

The Pratt et al. (1999, Experiment 2) data were analysed in the same manner as the data of Experiment 3 data. This analysis revealed a pattern of results similar to the findings of the Experiment 3. A marginal momentum effect was present only when the upper right location was cued (i.e., a short cue-target distance), $F(1,108) = 5.88$, MSe = 572.93, $p < .05$. When the cue appeared at any other location, the momentum effect was not significant (lower right: $F(1,108) = 2.38$, lower left: $F(1,108) = 3.94$, upper left: $F(1,108) < 1$, all ps > .05).

Analyses of individual participant data showed that while all 13 participants demonstrated a reliable IOR effect (100%), all Fs > 7.05, all ps <.01, only three of the participants (23%) demonstrated a reliable momentum effect, all Fs < 5.33, all ps < .025.

Although robust IOR was observed, in the present experiment, the momentum effect was again specific to a single cue-target direction, and was present for only a minority of participants. Re-analysis of Pratt et al.'s Experiment 2 data revealed a similar pattern of results. Together the data argue for the conclusion that although RT can be facilitated at an uncued location opposite to the cued location, this reputed momentum effect is unrelated to the IOR effect and is neither robust nor reliable.

General Discussion

Experiments 1 to 3, were designed to investigate whether facilitation at an uncued location (i.e., attentional momentum), rather than inhibition at a cued location, was underlying the IOR effect and to determine the boundary conditions of such a facilitatory effect. In Experiment 1, this attentional momentum effect was explored by varying the duration of the peripheral cue, effectively altering its relationship to the centrally located fixation stimulus. According to the momentum hypothesis, when the fixation cue occurred after the offset of the peripheral cue, an analog movement of attention should have proceeded from the cued location to fixation (Pratt et al. 1999). The uncued opposite location would then be along the path of attention, and the shortest RT would be expected at that uncued opposite location in comparison to any other location in the display. When the peripheral cue duration exceeded the fixation cue duration, it was not known whether attention would remain at the cued location, or whether the attentional path would revert toward the cued location or simply be disturbed. Importantly, neither a facilitatory effect at the opposite uncued location nor an IOR effect at the cued location was predicted.

A strong and reliable IOR effect was found across all cue durations, however, no momentum effect was found for any of the cue durations. Thus, the first test of attentional momentum suggested that the attentional momentum effect may not be robust, reliable, or an important component of the IOR effect.

Although Experiment 2 produced a momentum effect, there are several problems for an attentional momentum account of the IOR effect. One, the momentum effect did not occur for all possible cue-target momentum directions, either in the present study or in that of Pratt et al. (1999, Experiment 1) whereas the IOR effect was robust across all cue-target directions. Two, the momentum effect did not occur for the majority of participants whereas the IOR effect occurred for the majority of participants. And three, the momentum effect was one-third the magnitude of the IOR effect. These findings suggested that the IOR effect and the momentum effect are not tightly linked and may, in fact, be independent phenomena with the momentum effect being weak and unreliable and the IOR effect being robust and reliable.

Experiment 3 was based on the Pratt et al.'s Experiment 2. The pattern of results replicated both the present Experiment 2 and Pratt et al.'s Experiment 2. A close inspection of the data revealed that the momentum effect occurred only for one of four cue-target directions, and for only a few participants. As before this weak momentum effect contrasted with a robust IOR effect.

Taken together the data from the present study and Pratt et al.'s experiments support the conclusion that the IOR effect and the attentional momentum effect are not linked in any important way. Indeed, it would appear that the IOR effect does not depend, in any way, on momentum away from the cued location and towards the opposite uncued location.

This conclusion is supported further when a correlational analysis of the data is conducted. Across all experiments with a single fixed cue-target distance (our Experiments 1 and 2, and Experiment 1 from Pratt et al.), a correlation was computed between IOR and the momentum effect. Each cue-target direction for each participant composed one paired data item. Since the attentional momentum hypothesis states that attentional momentum is the primary component underlying IOR, a strong relationship should exist between the two effects. However, the correlation between IOR and attentional momentum differed significantly from a correlation of 1.0, $r(160) = 0.22$, $p < .001$. As such, only 5% of the variance was accounted for by assuming a relationship between the IOR effect and the momentum effect. Considering only the cue-target directions from these experiments in which a momentum effect was shown to be statistically present yields an even weaker correlation, $r(26) = .15$, $p < .001$. No relation between the momentum effect and the IOR effect is found, $r(53) = -0.02$, $p < .001$, even when all positive cases of momentum are included to increase power. Clearly then, even when the most liberal correlational test is conducted, there is no support for the proposal of Pratt et al. (1999) that the momentum effect underlies IOR.

It is possible that the attentional momentum effect reflects a strategic or stereotypical form of responding that is adopted by a small proportion of the participants. There are at least two lines of evidence to support this view. First, when the momentum effect was observed it occurred only in one of four possible cue-target directions. Second, both for our study and the study of Pratt et al. there was no reliable pattern across experiments as to the cue-target direction that would exhibit an momentum effect. Analyses of four experiments (Experiments 2 and 3 and Pratt et al.'s Experiments 1 and 2) revealed that momentum effects occurred for only 10 of the 67 (15%) participants. This contrasts with the fact that 49 of the 67 (73%) participants produced IOR. Moreover, for the 15% of the participants that produced a momentum effect, this effect appeared in only one of four possible cue-target directions, with no consistency across experiments as to which cue-target direction would produce the effect. Therefore, given the small percentage of participants exhibiting the attentional momentum effect, the fact that the momentum effect does not occur in all possible cue-target directions, and that the momentum effect varies in its direction from experiment to experiment, it is not surprising to discover that it is often not present.

Having confirmed that IOR is the result of an inhibitory mechanism operating at the cued location and not from a facilitatory effect at an uncued location, the remainder of this thesis will consider whether IOR can occur at more than one location in a visual search task and in addition, it will explore the boundary conditions under which multiple location IOR can operate.

CHAPTER 4: ATTENTION AND INHIBITION OF RETURN AT MULTIPLE LOCATIONS

Fundamental to the notion that IOR facilitates visual search is the assumption that IOR must co-occur at several previously attended locations. As noted in the literature review, tests of this assumption have produced conflicting results. For instance, Posner and Cohen (1984) reported that IOR can occur at two simultaneously cued locations (see also Maylor, 1985; Danziger & Kingstone, 1999). And more recently Wright and Richard (1996) have observed an inhibitory effect that may co-occur at up to four simultaneously cued locations. Pratt and Abrams (1995), however, reported that IOR does not appear at more than one location at any given time. In their study, there were two possible target locations. A peripheral cue could occur either once at one location and then once at the alternative location, or the peripheral cue could occur twice, in succession, at the same location. For both cue sequences inhibition was observed only at the most recently cued location, suggesting that IOR plays a relatively small role in searching complex environments.

This conclusion was challenged by Tipper et al. (1996). They suggested that because Pratt and Abrams (1995) used only two possible target locations, a flexible biological system would not inhibit attention from returning to both locations, as this would have the effect of slowing RT overall. Tipper et al. (1996) repeated the Pratt and Abrams (1995) study but increased the number of possible target locations from two to four. On each trial, three of the four locations were cued sequentially. The results revealed that inhibition occurred at each of the cued locations, suggesting that IOR can co-occur at multiple sites and facilitate visual search.

Importantly, the results of the Tipper et al. (1996) study were shown to be anything but definitive. Abrams and Pratt (1996) suggested that by cuing three of the four locations, the Tipper et al. study may have permitted participants to group all cued locations under a single "umbrella" of inhibition. (Note, that a similar argument can be made against the studies where multiple locations were simultaneously cued such as Posner and Cohen, 1984; Wright and Richard, 1996.) Abrams and Pratt (1996, Experiment 3) repeated the Tipper et al. (1996) experiment, incorporating two modifications. First, the number of possible target locations was increased from four to six; and second, to further prohibit grouping of cued locations, three nonadjacent locations were always cued sequentially. Their results indicated that IOR occurred only at the most recently cued location, suggesting again that IOR may not play an important role when searching complex environments.

In reviewing the IOR literature, Danziger et al. (1998) noticed that the observers had always known in advance the number of cues that would precede target onset. For example, in the Abrams and Pratt (1996) study, observers always knew that the target would appear after the third cue. Given that the goals or intentions of an observer can override attentional capture by abrupt peripheral onsets (Yantis & Jonides, 1996), Danziger et al. hypothesized that observers might be discouraged from attending to the cue onsets when they knew in advance that the cues would not be targets. If attending to peripheral onset events is a necessary precursor to the occurrence of IOR at multiple locations, then advance knowledge of cue number might be a critical factor in determining whether multiple IOR is or is not observed.

In three experiments, and using two different paradigms, Danziger et al. (1998) introduced a manipulation that ensured that observers would be uncertain as to whether an onset event was a cue or a target. They reasoned that this manipulation might force observers to attend to each onset event in search of a target, and when a target was not found, the attended location would be tagged with IOR. In each of the experiments, there were five possible target locations marked by placeholders in the periphery. The placeholders were organized around an imaginary circle with a fixation stimulus at the center. The paradigm was similar to the one used by Posner and Cohen (1984) with outline placeholders present and cuing accomplished by increasing the luminance (i.e., brightening) of one of the placeholders. The task in Experiment 1 was to detect the onset of a target, an asterisk, as illustrated in Figure 11. The task in Experiment 2 was to discriminate whether the target was an "x" or a "+".

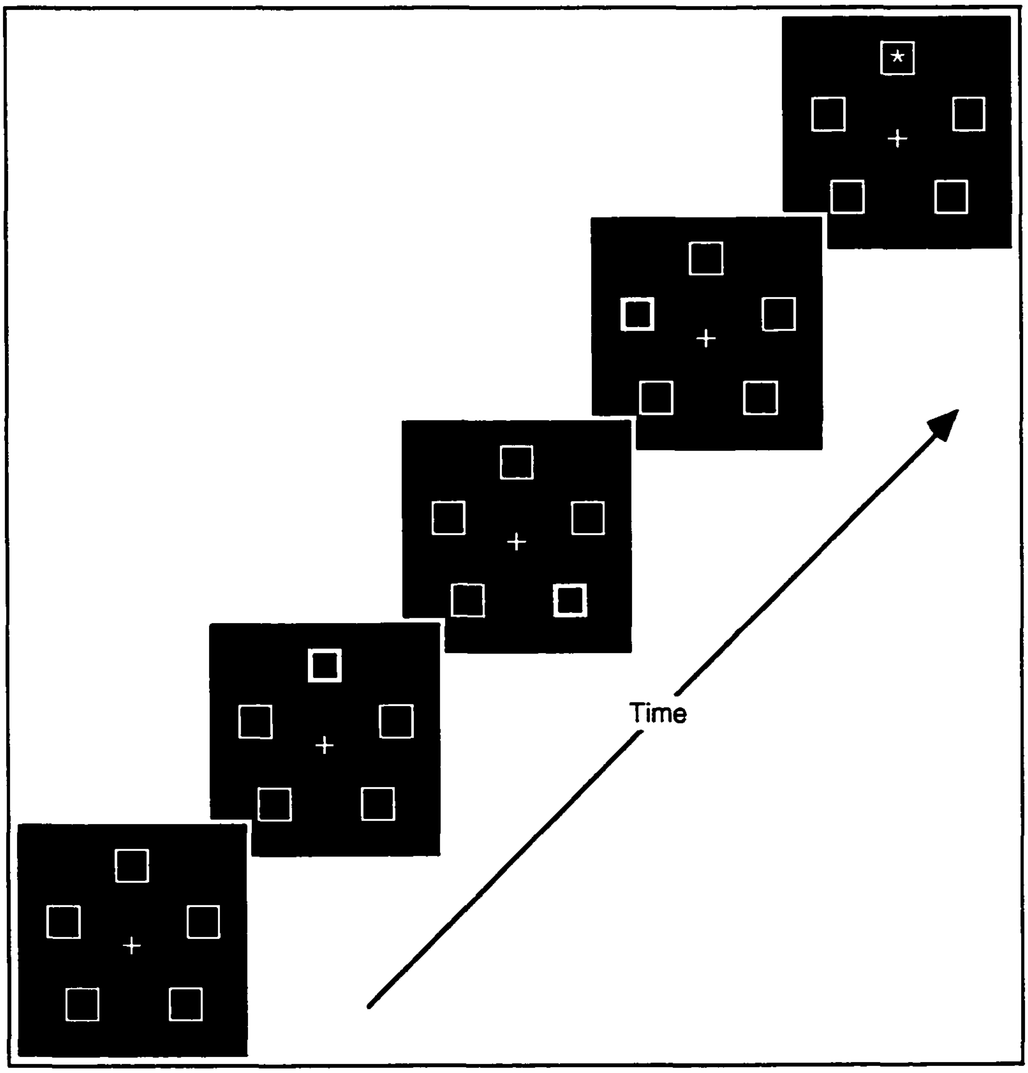

Figure 11. Illustration of a three-cue trial in the Danziger, Kingstone, and Snyder (1998, Experiment 1) study. Cuing is accomplished by brightening the outline of the placeholder (shown as a thickened line). In this example, the target (an asterisk) appears at the first of three sequentially cued locations.

In Danziger et al.'s Experiment, 3 a novel paradigm was tried. Here, the placeholders were letter "O"s and cuing was accomplished by simultaneously removing an "O" and replacing it with a letter "Z". The task in this experiment was to detect the onset of the target letter "N", as illustrated in Figure 12. Although this task could be described as a detection task, it is more correctly classified as a discrimination task because observers effectively had to determine whether the onset event was a "Z" (i.e., a cue) or an "N" (i.e., a target). This discrimination was difficult as the cue is simply a rotated version of the target.

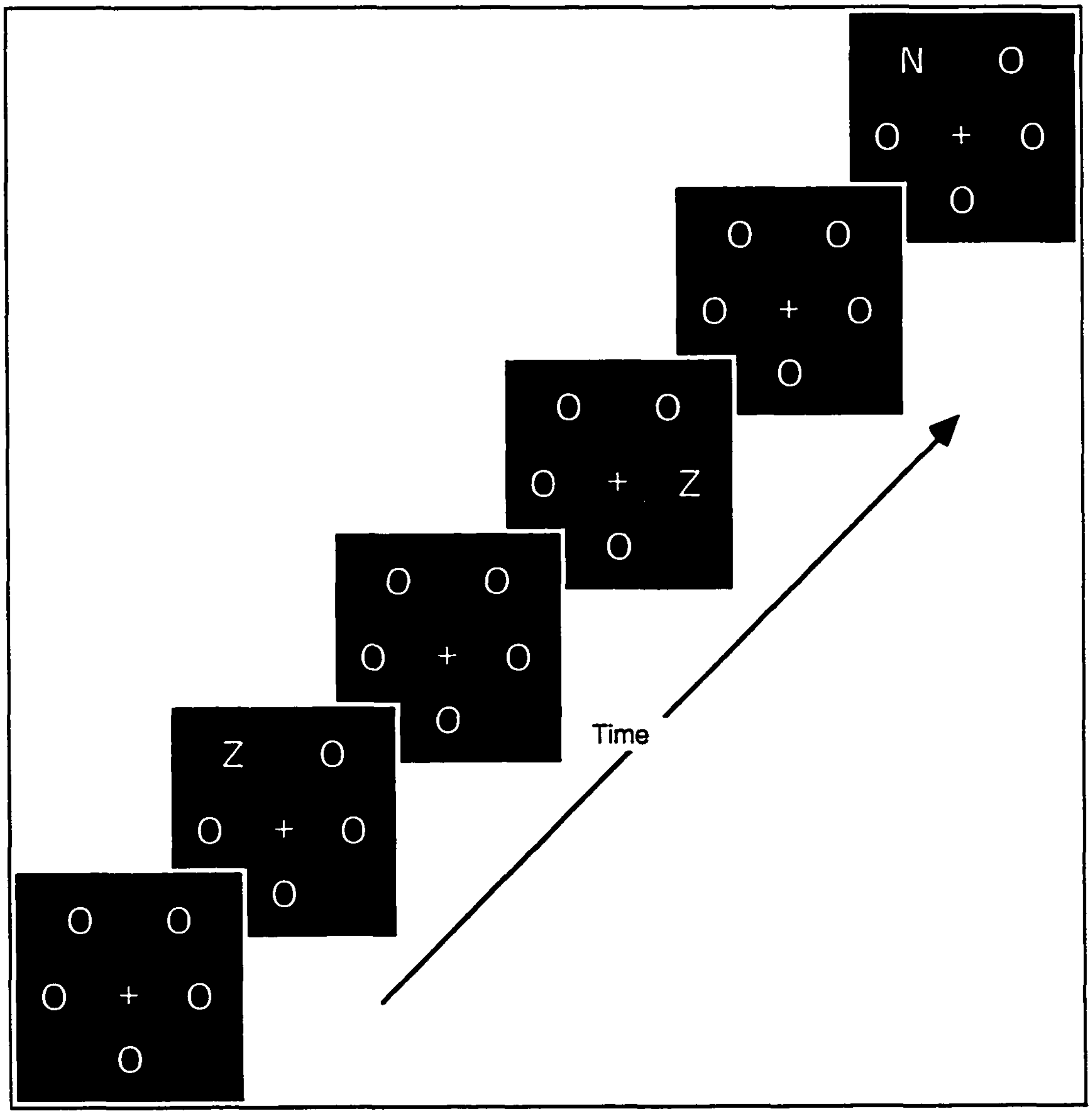

Figure 12. Illustration of a two-cue trial in the Danziger, Kingstone, and Snyder (1998, Experiment 3) study with the target appearing at the first of two sequentially cued locations.

Prior to target onset, one, two, or three of the target placeholders could be cued in sequence, or target onset might occur without any cue. An important difference between this investigation and all previous IOR studies was that the number of cues preceding target onset varied randomly from trial to trial. When multiple peripheral cues were presented, they occurred in sequence, with each cue coinciding with the time that a target could occur. Therefore on any given trial, when a stimulus event occurred in the periphery, participants presumably had to direct their attention to the stimulus to determine whether it was a cue or a target. Danziger et al. (1998) hypothesized that when the peripheral event was found to be a cue, and not a target, IOR would generated at that inspected (i.e., attended) location.

The results of this sequential visual search study were conclusive: IOR occurred at all of the cued locations. That is, IOR was observed at one cued location when there was one cue, at two cued locations when there were two cues, and at three cued locations when there were three cues. Importantly, and in contrast to Abrams and Pratt (1996), it was discovered that this multiple IOR occurred whether or not the cued locations were spatially contiguous demonstrating that spatial grouping was not responsible for the effect. And finally, the magnitude of the IOR effect was strongest at the most recently cued location and weaker at the two previously cued locations. This result held for Danziger et al.'s (1998) simple detection task (Experiment 1) as well as for the discrimination tasks (Experiments 2 and 3).

Thus, the Danziger et al. study demonstrated that IOR can co-occur at multiple non-spatially continuous locations in a sequential visual search paradigm. Furthermore, they considered that a critical component of their discovery was the fact that observers had to attend to the peripheral onsets events because they were uncertain as to whether an onset event was a cue or a target. However, although they concluded that the attentional allocation to peripheral onsets was crucial for the observation of multiple IOR, this hypothesis was not in fact tested.

The important question regarding the necessary role of attention in generating multiple location IOR is addressed in the following three experiments. Based on the rationale of Danziger et al., in Experiment 4, it was expected that multiple IOR should be eliminated when observers can predict whether an onset event was a cue or a target. However, multiple IOR was not eliminated possibly because observers were attending peripheral onsets not for the purpose of discriminating cue onsets from target onsets, but as a means of tracking the cue onsets in preparation for the predicted target event. This hypothesis was tested successfully in Experiment 2. The finding of a facilitatory effect at short cue-target delays in Experiment 3 confirmed that attention was allocated to each peripheral onset.

Experiment 4

Danziger et al. (1998) reasoned that multiple IOR was generated in their study because observers could not predict whether an onset event was a cue or a target. Thus in Experiment 4 , it was hypothesized that multiple IOR should be eliminated when observers can predict whether an onset event is a cue or a target.

Using the Danziger et al. (1998, Experiment 3) paradigm, observers were tested in two sessions. In one session (random), the number of peripheral sequential cues preceding target onset varying randomly from trial to trial and, thus, observers were unable to predict whether an onset event was a cue or a target. According to Danziger et al., this manipulation should force observers to attend to each onset event, which in turn should generate multiple IOR. In a second session (blocked), the number of peripheral cues preceding target onset was held constant across a block of trials and here observers were able to predict whether an onset event was a cue or a target. According to Danziger et al., observers should not need to attend to each onset event, which in turn should abolish the occurrence of multiple IOR.

Method

Participants

Twenty undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Apparatus and Stimuli

In this and all subsequent experiments reported in this thesis, stimuli were displayed on a 40 cm VGA monitor controlled by a computer. In keeping with Danziger et al. (1998, Experiment 3), the stimulus display consisted of a black background with five light-gray letter "O"s, each having a diameter of 1.5° of visual angle, serving as placeholders. The "O"s were placed equidistantly around an imaginary circle with a radius of 6.0° from the center of the circle to the center of each "O". The first "O" was located at an angle 36° to the right of the central vertical meridian and the last "O" was located at an angle of 36° to the left of the vertical meridian. A 0.5° x 0.5° light-gray central fixation cross marked the center of the imaginary circle. The cues were light-gray letter "Z"s measuring 1.0° in width and in height. The target was a light-gray letter "N", also measuring 1.0° in width and in height. RT was recorded on the computer and measured in msec.

Procedure

The following procedure held across this and all subsequent experiments described in this thesis. Participants were seated in front of a keyboard and display screen at a viewing distance of 57 cm. They were instructed (a) that peripheral cues did not predict where a target would appear (i.e., the target could occur equiprobably at any of the placeholder locations); (b) to maintain fixation throughout the trial; and (c) to execute a response as quickly and as accurately as possible. They were further instructed to take a rest break upon completion of a block of trials. Each block of trials was initiated with a keypress. Response feedback was provided, with a 200 msec error tone sounding when participants responded prior to target onset or when they failed to respond to the target. The error tone was easily distinguished from the warning tone.

In the present experiment the response task was to press the space bar when the target (a letter "N") was detected. The target remained on the screen until a response was executed or 1500 msec had elapsed, whichever came first. At the start of each block of trials, a message appeared on the monitor, informing the participant of the number of cues that would occur in that block of trials. In the random session, the message read, "In the next block of trials, the target will appear after either one, two, or three cues occur." In the blocked session, the message indicated the specific number of cues preceding target onset. An experimental session lasted approximately 50 minutes.

All trials began with a 100 msec warning tone. Five hundred msec after the onset of the warning tone, one of the locations was cued (first cue) by simultaneously changing an "O" to a "Z" in the same location. The "Z" remained on the screen for 750 msec before it was replaced with an "O". Following a 750 msec delay, either the target (an "N") appeared or a different location was cued (second cue) by changing an "O" to a "Z" for 750 msec, and then changing the "Z" back to an "O". Following a 750 msec delay, either the target "N" appeared or a different location was cued (third cue) by changing an "O" to a "Z" for 750 msec, and then changing the "Z" back to an "O". Following a 750 msec delay either a target "N" appeared or no target occurred (a catch trial). Note that in this cuing sequence a 1500 msec SOA separated a succession of two cues or a cue and a target. Up to three cues could precede target onset. In this and in all subsequent multiple IOR experiment in the thesis, on each trial, the location of a cue and the location of a target were randomly selected from among all possible placeholders, with the provision that the same placeholder was never cued twice on the same trial.

All trials were terminated upon execution of a response or 1500 msec after the target onset, whichever came first. A 200 msec error tone, which was easily distinguished from the warning tone, provided error feedback when participants either anticipated a target or failed to respond to a target. Figure 12 illustrates a trial in which two cues preceded target onset, with the target appearing at the location that was cued first.

Design

Participants were tested once in the random session with the number of cues varying randomly from trial to trial, and once in the blocked session with the number of cues held constant within a block of trials. Participants never performed both sessions on the same day. The order of sessions was counterbalanced across participants. In a single day of testing, participants received 10 practice trials (one-, two-, and three-cue trials in the random session; two-cue trials in the blocked session) followed by 15 blocks of 32 test trials, for a total of 480 test trials. These 480 test trials were composed of an equal number of one-, two-, and three-cue trials, resulting in 160 trials per cue condition plus 30 catch trials in which the target never appeared. The cues did not predict target location and the target could occur equiprobably at any of the five possible locations. Therefore, on trials when one location was cued prior to target onset (i.e., on one-cue trials), the target would appear 32 times at the cued location and 32 times at each of the four uncued locations. Similarly, for the three-cue trials the target would appear 32 times at each of the three cued locations and 32 times at each of the two uncued locations.

In the blocked session, the cue number for each block was randomly generated with the constraint that the same cue number never repeated in successive blocks. Catch trials were distributed equally among the different cue numbers. In the random session, catch trials always occurred after three cues. (Note that in the random session catch trials were not required after one cue because a second cue could occur, and similarly, catch trials were not required after two cues because a third cue could occur.)

Results

Before presenting the performance data, it is important to clarify the terminology used to describe the results. If only one cue occurred prior to target onset, and the target occurred at the cued location, this cued location is referred to as "one-back" from target onset. When two cues occurred in sequence prior to target onset and the target occurred at the location that was cued just prior to target onset, again this location is referred to as a cued "one-back" location. If the target occurred at the second last location that was cued, this cued location is referred to as a cued "two-back" location. A similar progression occurs for three cues trials. The target location illustrated in Figure 12 is a cued two-back location, following a sequence of two cues.

Separate repeated measures ANOVAs were performed for each of the cued-back locations (one-back through to three-back). For cued one-and two-back trials, a three-factor ANOVA was conducted with target location (cued one-back or cued two-back vs. uncued), session (random, blocked), and number of cues as factors. For the cued three-back trials, a two-factor ANOVA was conducted with target location (cued three-back vs. uncued) and session (random, blocked) as factors. Note that a main effect of target location indicates the presence of IOR. That is, IOR was observed when RT was longer at a cued-back location than at an uncued location. Mean correct RT for target detection in the random and blocked sessions as a function of target location and number of cues is presented in Figure 13, 14, and 15, for cued one-, two-, and three-back trials, respectively.

Cued one-back trials

The main effect of target location was significant, F(1, 19) = 170.51, MSe = 403.05, $p < .001$, indicating that RT was longer when a target appearing at a cued location (449 msec) than at an uncued location (415 msec). This difference in RT reflects the presence of IOR. The main effect of session was significant, F(1, 19) = 59.05, MSe = 9714.28, $p < .001$, reflecting the fact that RT was shorter in the blocked session (383 msec) than the random session (481 msec). The main effect of number of cues was significant, F(2, 38) = 52.77, MSe = 1004.49, $p < .001$, indicating that overall RT declined as the number of cues increased (458, 431, and 406 msec for one, two, and three cue trials, respectively). A similar warning signal effect was observed by Danziger et al. (1998) and it reflects the fact that the temporal uncertainty regarding when a target will occur is reduced as the number of cues is increased.

There was also a significant target location x session interaction, F(1, 19) = 8.08, MSe = 476.30, $p < .05$, indicating that the IOR effect was larger in the blocked session (42 msec) than in the random session (26 msec). Planned contrasts confirmed that all the IOR effects were significant for the blocked (37, 37, and 51 msec for one-, two-, and three-cue trials, respectively) and for the random sessions (12, 30, and 36 msec for one-, two-, and three-cue trials, respectively), all Fs > 42.04, all ps < .001.

The target location x number of cues interaction was also significant, F(2, 38) = 4.54, MSe = 397.14, $p < .05$, reflecting that the magnitude of IOR increased as the number of cues increased (24 msec for one-cue, 34 msec for two-cue, and 43 msec for three-cue trials). Finally, there was a significant session x number of cues interaction, F(2, 38) = 89.83, MSe = 666.49, $p < .001$, consistent with the fact that RT decreased in the random session as the number of cues increased, but a similar decline in RT as a function of cue number was not observed in the blocked session. This interaction between session and cue number (along with the main effects of session and cue number) reflects the warning signal effect described above. The interaction occurred because the effect was not produced in the blocked session as participants were always prepared to respond to the target whether it occurred after one, two, or three cues because they always knew in advance when a target would occur.

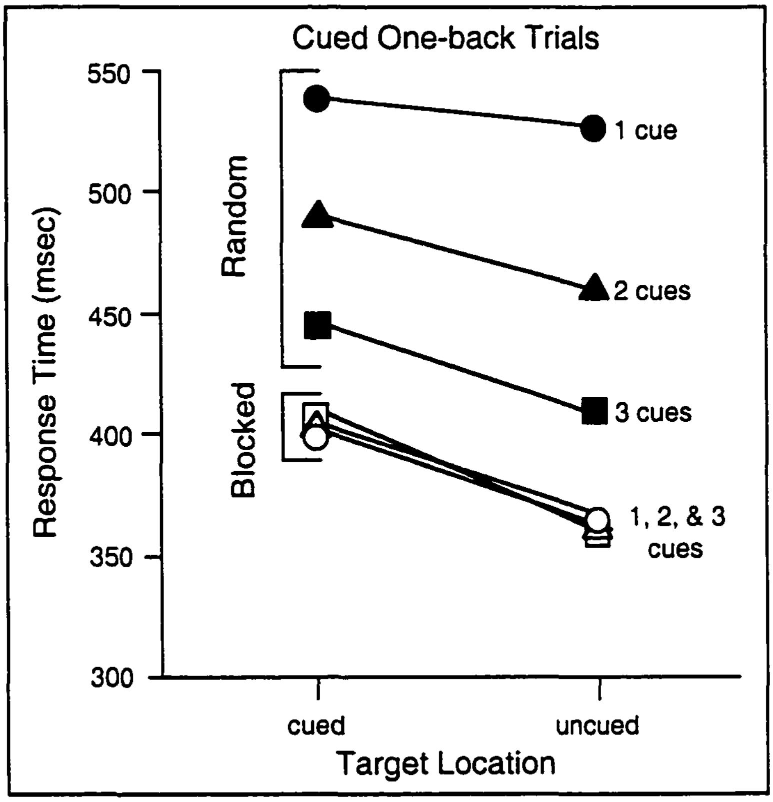

Figure 13. Mean correct RT for cued one-back and uncued target locations on one-, two-, and three-cue trials in the random and blocked sessions of Experiment 4. Cued one-back refers to target onset at the last location that was cued prior to target onset. Uncued refers to target onset at a location that was not cued.

Cued two-back trials

A significant main effect was observed for target location, F(1, 19) = 53.96, MSe = 424.46, p < .001, with RT longer for a target at a cued location (424 msec) than at an uncued location (400 msec). The main effect of session was again significant, F(1, 19) = 36.56, MSe = 6299.08 p < .001, reflecting shorter RT in the blocked session (374 msec) than the random session (450 msec). The main effect of number of cues was significant, F(1, 19) = 29.43, MSe = 829.62, p < .001, indicating a decline in RT as the number of cues increased (424 and 399 msec for two and three cues, respectively). The interpretation of each effect is the same as above, except that the main effect of target location indicates that IOR was observed at the location cued second from last before the target appeared. Neither the target location x session interaction, F < 1, nor the target location x number of cues, F(1, 19) = 3.88, MSe = 306.70 p > .06, nor target location x session x number of cues, F(1, 19) = 1.15, MSe = 183.70 p > .2, were significant, indicating that the IOR effect (24 msec overall) was statistically the same for both blocked and random sessions and for two-cue and three-cue trials.

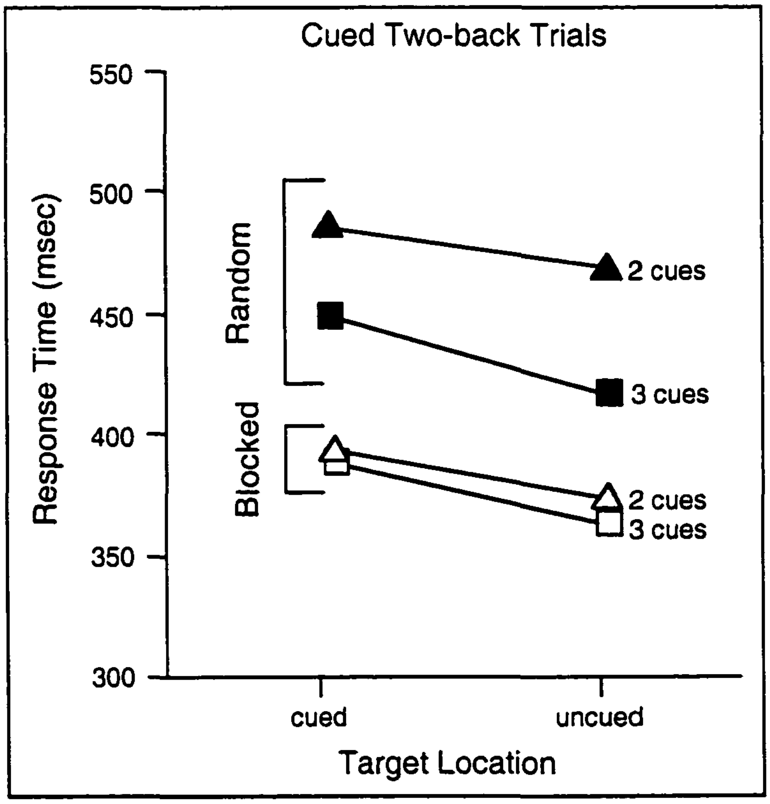

Figure 14. Mean correct RT for cued two-back and uncued target locations on two- and three-cue trials in the random and blocked sessions of Experiment 4. Cued two-back refers to target onset at the second location that was cued prior to target onset.

There was, however, a significant session x number of cues interaction, F(1, 19) = 37.06, MSe = 401.65, p < .001, reflecting, as before, the fact that the cues produced a warning signal effect in the random session but not in the blocked session.

Cued three-back trials

A significant main effect of target location was revealed, F(1, 19) = 68.24, MSe = 237.25, p < .001, with RT longer for a target at a cued location (413 msec) than at an uncued location (385 msec). The main effect of session was significant, F(1, 19) = 22.40, MSe = 2728.37 p < .001, reflecting shorter RT in the blocked session (426 msec) than the random session (371 msec). The interpretation of each effect is the same as above, except that the main effect of target location indicates that IOR was observed at the location cued third from last before the target appeared.

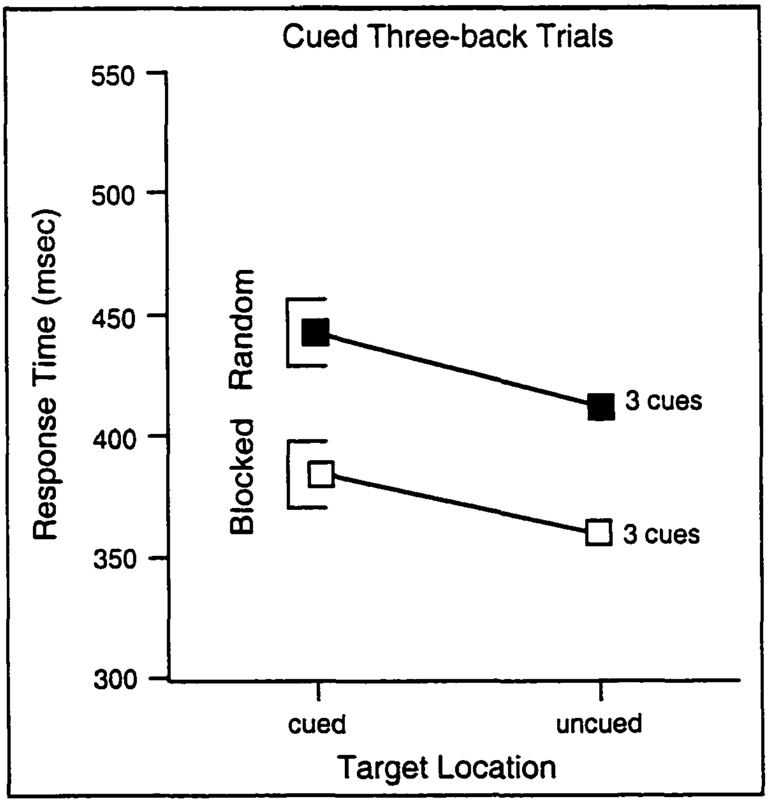

Figure 15. Mean correct RT for cued three-back and uncued target locations on three-cue trials in the random and blocked sessions of Experiment 4. Cued three-back refers to target onset at the third location that was cued prior to target onset.

The target location x session interaction, F < 1, was not significant, indicating that the IOR effect (28 msec overall) was statistically the same for both blocked and random sessions.

Response accuracy

Error rates were low in both the random session (2.1%) and the blocked session (2.5%). Errors were either false alarms (i.e., a response prior to target onset) anticipations (i.e., a response less than 100 msec after target onset), or a missed response (no response within 1500 msec of target onset). False alarms accounted for the majority of errors in both the random and the blocked sessions (1.8% and 1.6%, respectively), with fewer errors occurring in both sessions as the result of anticipations (less than 0.1% and 0.7%, respectively), and missed responses (0.3% and 0.2%, respectively). Error data were analysed with a one-factor repeated measures ANOVA for each session with trial type (one-cue cued one-back, one-cue uncued, two-cue cued one-back, etc. and no target - catch trials). For the random session, there was a significant main effect of trial type, $F(9,171) = 6.62$, MSe = 0.001, $p < .01$.$F(11,209) = 2.65$, MSe = 0.001, $p < .001$. There was also a significant main effect of trial type for the blocked session, $F(11,209) = 2.65$, MSe = 0.001, $p < .001$. Importantly, post-hoc analyses revealed that accuracy did not differ between cued and uncued locations for either the random or the blocked sessions, all Fs < 1. Thus, the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

Results from the random session revealed that IOR was present at all of the cued locations. This finding replicated Danziger et al. (1998) and agrees with their hypothesis that when target onset is unpredictable each cued location is inspected and tagged with IOR. Contrary to their hypothesis, though, the results from the blocked session revealed that IOR was present at each of the cued locations, with the magnitude of IOR mirroring that found in the random session. This finding would appear to refute the Danziger et al. hypothesis that attention needs to be directed to the cued locations in order for multiple IOR to be generated.

Before rejecting an attentional account of multiple IOR, however, it is necessary to confirm that attention was not oriented to the cued locations in the blocked session. It could be argued that in the blocked session, participants simply did not to use the information provided to them regarding target onset. Instead they may have directed attention to each onset event in search of a target event just as they did in the random session. This argument is not, however, supported by the data. In the random session there was a warning signal/response preparation effect, indicating that a participant's uncertainty as to when a target would occur declined with each additional cue. In the blocked session, however, there was no warning signal/preparation effect as cue number increased. Instead, RT was consistently shorter in the blocked session than the random session and did not vary with the number of cues. Presumably this was because in the blocked session observers always knew when a target would occur, and selectively prepared for that event. Hence, the data indicate that in the blocked session participants were using the advance knowledge they were afforded to prepare for a target.

Interestingly, this conclusion begs the question as to how participants in the blocked session were able to use their advance knowledge to prepare for a target. It would seem that in order to prepare for a target after a fixed number of cues, participants would need to keep track of each cue as it occurred. Recognition of this point raises the possibility that attention may have been directed to the cued locations in the blocked session; not for the purpose of discriminating cued onsets from target onsets as hypothesized in the random session, but as a means of tracking the cue onsets in preparation for the predicted target event.

Thus, it is possible that in Experiment 4, participants were forced to attend to cued locations in both the blocked and random sessions, albeit for different reasons. In the blocked session, it was to track the passage of cues so that the advance information regarding target onset could be utilized. In the random session, it was to inspect the cued locations in order to assess whether the onset event was or was not a target. If, as Danziger et al. argue, multiple IOR occurs when attention is directed to cued locations, then this would explain why IOR was observed at multiple locations in both the blocked and random sessions.

From this it follows that if the need to track cue onset in the blocked session is eliminated, for example, by providing a running total of cue onset at fixation, then multiple IOR in the blocked session should be eliminated. This prediction holds because participants would not need to attend to the peripheral cue onsets, and therefore, IOR should not be observed at each of the cued locations. On the other hand, multiple IOR should continue to be observed in the random session because participants will still need to attend to each onset event to discriminate whether it is a cue or a target. Experiment 5 was designed to test these predictions.

Experiment 5

Experiment 5 was a replication of Experiment 4, with one exception. A number was presented at fixation that effectively enumerated the cues as they occurred (see Figure 16). For instance on a three-cue trial, when the first cue occurred in the periphery, the fixation cross was replaced with the number "1." When the cue was offset, the number was replaced with a fixation cross. When the second cue occurred, the cross was replaced with the number "2," and when the third cue occurred the fixation cross was replaced by a number "3." And when the target occurred the fixation cross was replaced by a number "4". The reasoning was that by enumerating cue onsets at fixation, participants in the blocked session would not need to track the peripheral onsets to accurately prepare for the target. (Note that in the blocked session, participants cannot perform the task correctly by simply responding to the number at fixation as catch (no target trials) trials were included). On the other hand, participants in the random session would still need to attend to each onset event because a target could occur unpredictably after one, two, or three cues. Thus, based on Danziger et al., the prediction was that multiple IOR would not be observed in the blocked session but it would be observed in the random session.

Method

Participants

Twenty undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Stimuli and procedure

All stimuli and events were the same as in Experiment 4, with one exception. Onset and offset of the number "1", "2", "3", or "4" now coincided with the onset and offset of a peripheral cue or target. (Note: on a catch trial, the number at fixation was incremented at 750 msec following the offset of the last cue.) Each number occurred in its proper order. The light-gray numbers were 1° high and 0.5° wide, except for the number "1" which was 1 pixel wide. Figure 16 illustrates the sequence of events on a two-cue target trial when the target appeared at the cued two-back location.

Participants in the blocked and random sessions were given the same instructions as in Experiment 1. In addition, participants were informed that: (a) a number at fixation would be onset/offset and this number would co-occur with cue and target onset/offset; (b) in the blocked session, the numerals at fixation enumerated the cue number and reliably indicated when a target onset could occur; and (c) in the random session, the same events occurred but because the number of cues preceding target onset varied randomly from trial to trial, the number at fixation was not informative with respect to target onset.

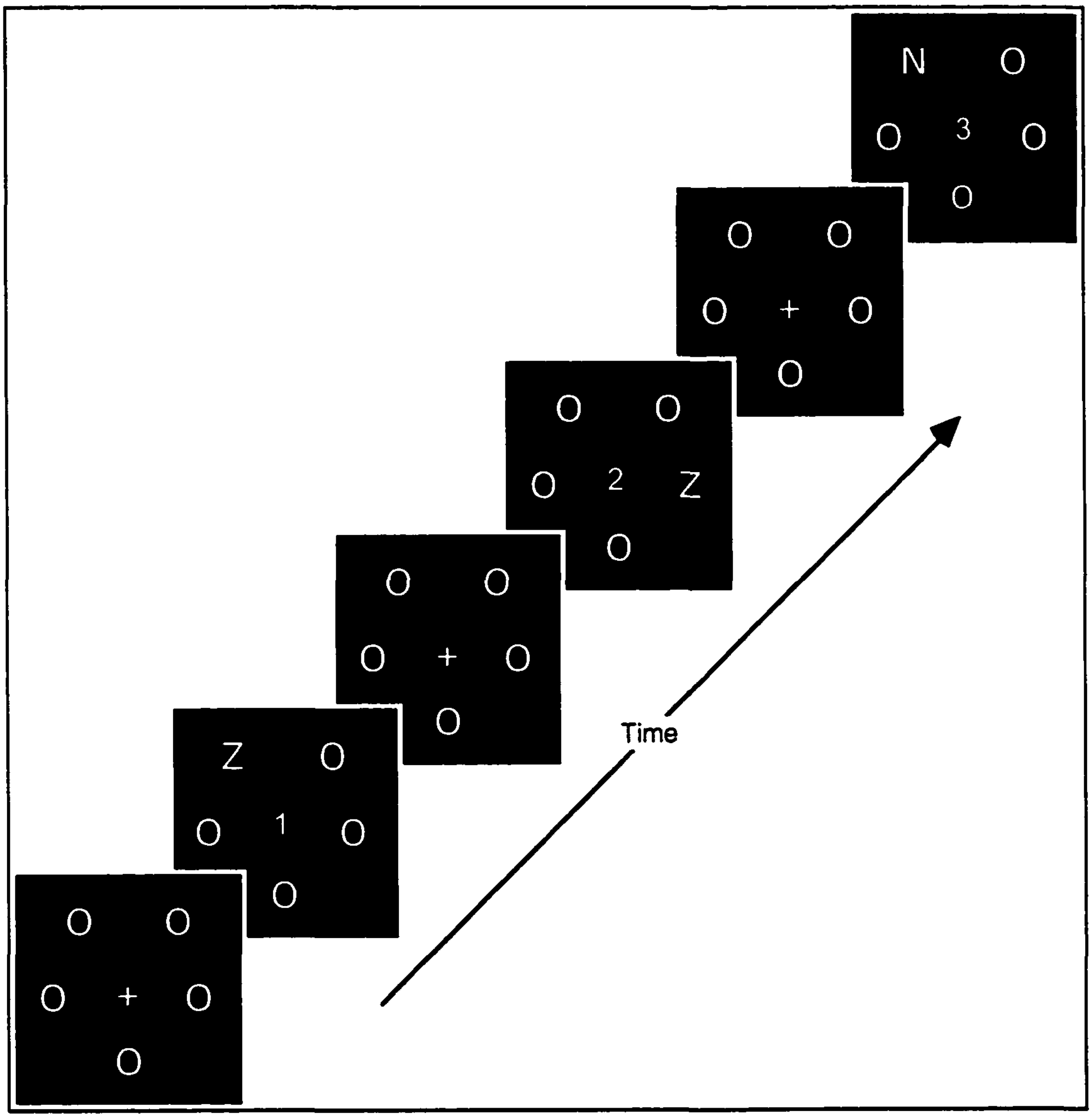

Figure 16. Illustration of a two-cue trial in Experiment 5 with the target appearing at a cued two-back location. In both the random and the blocked sessions, the fixation stimulus effectively enumerates the cues.

Results

Data analyses were conducted exactly as in Experiment 4. Mean correct RT for target detection in the random and blocked sessions as a function of target location and cue number are presented in Figures 17, 18, and 19 for cued one-, two-, and three-back trials, respectively.

Cued one-back trials

As was the case in Experiment 4, main effects of target location, F(1, 19) = 54.06, MSe = 505.59, $p < .001$, session, F(1, 19) = 204.47, MSe = 6621.51, $p < .001$, and number of cues, F(2, 38) = 118.29, MSe = 710.56, $p < .001$, were significant. As in Experiment 4, these main effects indicated that RT was: shorter in the blocked than in the random session; longer at the cued versus uncued location (i.e., IOR); and decreased as the number of cues increased.

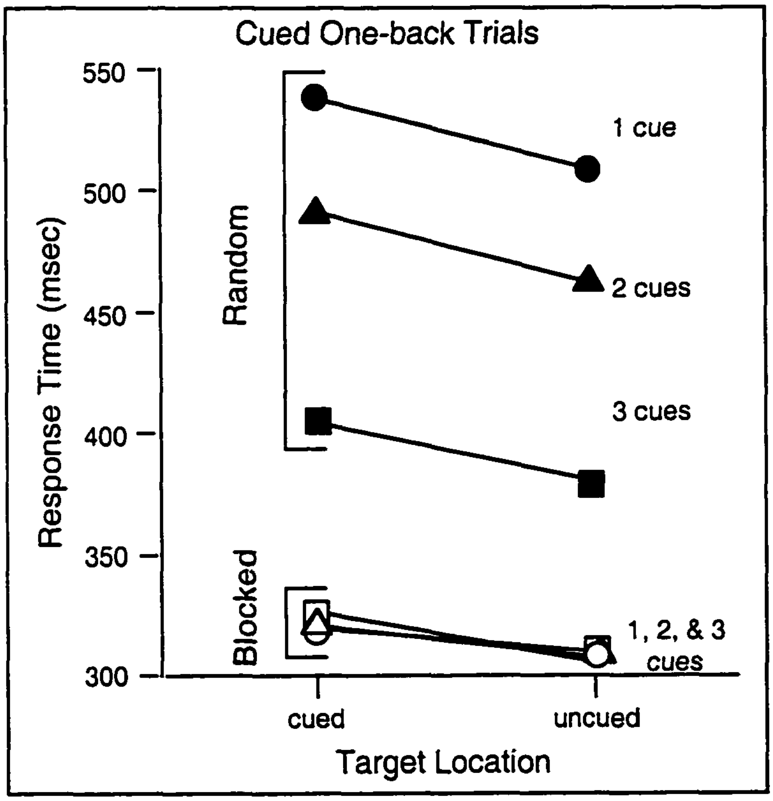

Figure 17. Mean correct RT for cued one-back and uncued target locations on one-, two-, and three-cue trials in the random and blocked sessions of Experiment 5.

There was also a significant target location x session interaction, F(1, 19) = 16.05, MSe = 179.13, $p < .001$, indicating that the IOR effect was now larger in the random session (28 msec) than in the blocked session (14 msec). Planned contrasts confirmed that the IOR effects were significant for both the blocked and the random sessions, Fs > 34.83, ps < .001. As in Experiment 4, the session x number of cues interaction was significant, F(1, 19) = 136.48, MSe = 696.13, p < .001, reflecting a warning signal effect in the random session but not in the blocked session. Neither the interaction between target location x number of cues, F < 1, nor between target location x session x number of cues, F(2, 38) = 1.71, MSe = 131.52, p > .1, approached significance.

Cued two-back trials

There were again significant main effects of target location, F(1, 19) = 19.97, MSe = 255.49, p < .001, session, F(1, 19) = 119.84, MSe = 4863.63, p < .001, and number of cues, F(1, 19) = 105.63, MSe = 648.28, p < .001. A target location x session interaction was observed, F(1, 19) = 11.51, MSe = 157.04, p < .01, reflecting that the IOR effect was larger in the random session (18 msec) than the blocked session (5 msec). Planned contrasts revealed that the IOR effect was significant in the random session, F(1, 19) = 41.33, MSe = 157.04, p < .001, but the IOR effect was not significant in the blocked session, F(1, 19) = 2.66, MSe = 157.04, p > .1. Finally, there was a significant session x number of cues interaction, F(1, 19) = 71.90, MSe = 864.71, p < .001, reflecting a warning signal effect in the random session but not in the blocked session.

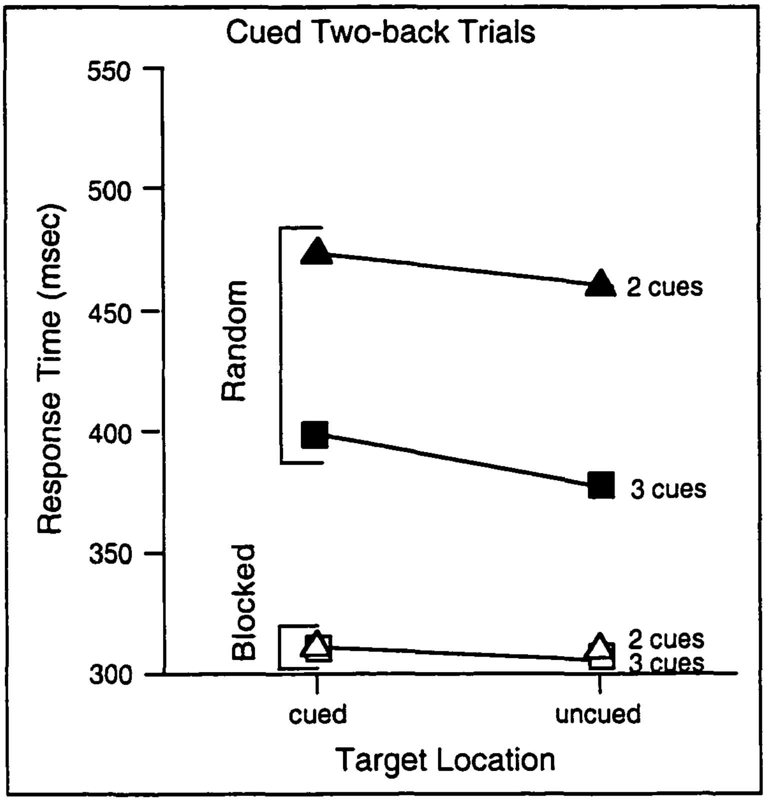

Figure 18. Mean correct RT for cued two-back and uncued target locations on two- and three-cue trials in the random and blocked sessions of Experiment 5.

Cued three-back trials

There were significant main effects of target location, F(1, 19) = 8.41, MSe = 201.52, p < .01, and session, F(1, 19) = 37.12, MSe = 3339.09, p < .001, but there was no significant target location x session interaction, F(1, 19) = 2.65, MSe = 293.97, p > .1. This lack of an interaction suggests that the IOR effect did not differ between the random session (15 msec) and the blocked session (3 msec). However, because the fewest trials occurred in the three-back condition, the lack of an interaction might merely reflect the fact that this analysis is insensitive to the fact that the IOR effect was five times larger in the random session than the blocked session. Planned contrasts revealed that the three-back IOR effect in the random session was significant, F(1, 19) = 8.12, MSe = 293.97, p < .05, but the IOR effect in the blocked session fell short of significance, F < 1.

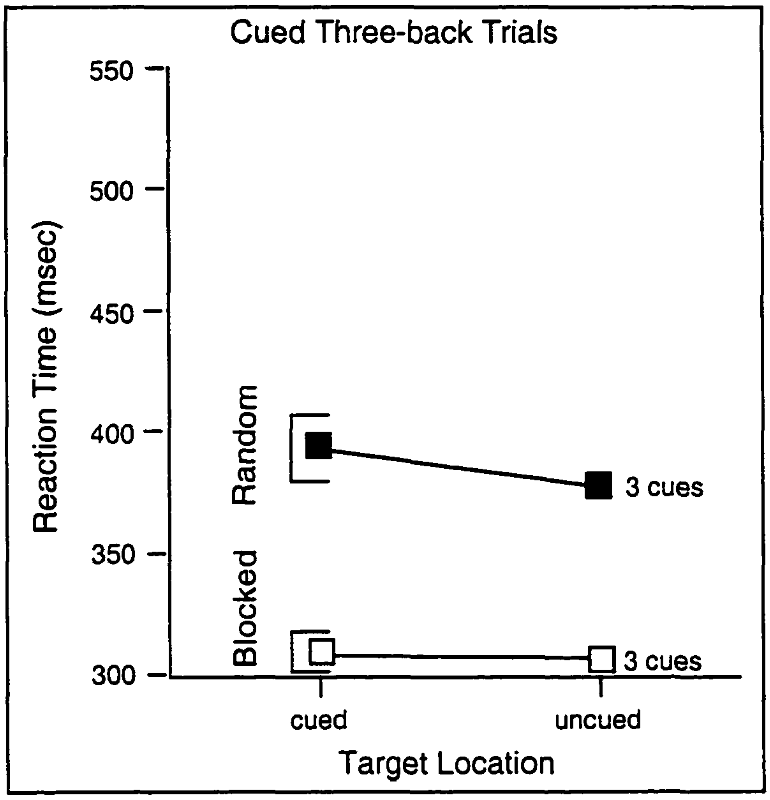

Figure 19. Mean correct RT for cued three-back and uncued target locations on three-cue trials in the random and blocked sessions of Experiment 5.

Response accuracy

As in Experiment 4, mean error rates were low in both the random session (2.5%) and the blocked session (2.7%). In the random session, false alarms accounted for the majority of errors in the random session (2.5%), with fewer errors occurring as the result of anticipations and missed responses (both less than 0.1% each). In the blocked session, most errors were anticipations (1.8%) with fewer errors occurring as the result of false alarms and missed responses (0.9% and less than 0.1%, respectively). Error data were analysed as in Experiment 4. For both the random and blocked sessions, there was a significant main effect of trial type, $F(9,171) = 8.42$, $MSe = 0.001$, $p < .001$ and $F(11,209) = 2.24$, $MSe = 0.001$, $p < .05$, respectively. Importantly, post-hoc analyses revealed that accuracy did not differ between cued and uncued locations for either the random or the blocked sessions, all $Fs < 2.35$, all $ps > .1$. Thus, the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

In Experiment 5, the need for participants in the blocked session to track the peripheral cues was eliminated, while the need for participants in the random session to inspect each onset event was maintained. This manipulation was intended to eliminate multiple IOR in the blocked session but not in the random session. The data from Experiment 5 agree with this prediction. Results from the blocked session revealed that a reliable IOR effect was present only at the most recently cued location, that is, the one-back location. There was no significant IOR effect at either the two-back location or the three-back location. On the other hand, results from the random session revealed that IOR was present at all three of the cued locations, as it had been in Experiment 4 and in Danziger et al. (1998). Thus, it would appear that multiple IOR is an attentional phenomenon that occurs when attention is committed to multiple onset events.

But prior to accepting the conclusion that multiple IOR is an attentional phenomenon that occurs when attention is allocated to multiple onset events, it is reasonable to require an objective behavioural measure that attention is committed to cued peripheral locations when multiple IOR occurs.

Experiment 6

The gold standard for confirming that attention has been allocated to a cued location is the finding that RT is shorter at a cued location than an uncued location when the cue-target SOA is 150 msec or less (Jonides, 1981; Müller & Rabbitt, 1989). Since the minimum cue-target SOA in Experiments 4 and 5 was 1500 msec, it was necessary to use the paradigm of Danziger et al. (1998, Experiments 1 and 2) into which a short final cue-target SOA could be incorporated.

Method

Participants

Twenty-six undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Stimuli and Procedure

The stimulus display consisted of a black background with five dark-gray outline placeholders measuring 1.5° of visual angle on each side and placed equidistantly around an imaginary circle (Danziger et al., 1998, Experiments 1 and 2; see Figure 11). The circle's radius, from its center to the center of each placeholder, measured 6.5°. The first placeholder was located at an angle of 36° to the right of the vertical meridian and the last placeholder was located at an angle of 36° to the left of the vertical meridian. A 0.5° light-gray central fixation cross marked the center of the circle. Cuing was accomplished by superimposing a light-gray outline placeholder over a dark-gray outline placeholder. The target was a 0.5° light gray asterisk.

Each trial began with a 100 msec warning tone. Cue duration was 100 msec; cue-cue SOAs were 600 msec; and the cue-target SOA was 100 msec as measured from the most recent cue. For example, on a three-cue trial, the target occurred 100 msec after the third cue, 600 msec after the second cue, and 1200 msec after the first cue. The target remained on the screen until a response was executed or 1500 msec had elapsed, whichever came first.

Design

Participants performed 10 randomly selected practice trials followed by 5 blocks of 34 test trials, for a total of 170 test trials. These 170 test trials were composed of 50 trials per cue condition (i.e., one-, two-, and three-cue trials plus 20 catch trials). On one-cue trials, the target occurred 10 times at the cued location and 10 times at each of the four uncued locations and so on and so forth for two- and three-cue trials. The selection of cue number (one to three cues), cue location, and target location were as in the random session of Experiments 4 and 5.

Results

As in Experiments 4 and 5, separate repeated measure ANOVAs, were performed for each of the cued-back locations (one-back through to three-back). Mean correct RT as a function of target location and number of cues is presented in Figure 20.

Cued one-back trials

The main effect of target location was significant, $F(1,25) = 5.73$, $MSe = 411.94$, $p < .05$, reflecting shorter RT at a cued location (392 msec) than at an uncued location (399 msec), that is, a facilitatory effect. And, as in the previous experiments, a significant main effect of number of cues occurred, $F(2,50) = 58.47$, $MSe = 404.65$, $p < .001$, reflecting the decrease in RT as the number of cues increased. The target location x number of cues interaction was not significant, $F< 1$, indicating that the facilitatory effect did not vary as a function of the number of cues presented.

Cued two-back trials

Significant main effects were observed for target location with longer RT at a cued location (418 msec) than at an uncued location (389 msec), that is, an IOR effect. The main effect of number of cues was also significant, $F(1,25)=10.67$, $MSe = 532.66$, $p < .01$. No significant session x target location interaction was observed, $F(1, 25) = 2.12$, $MSe = 453.72$, $p > .1$, reflecting that the IOR effect did not vary as a function of the number of cues.

Cued three-back trials

There was a main effect of target location, F(1, 25) = 7.12, MSe = 691.67, $p < .05$, with RT longer at a cued location (398 msec) than at an uncued location (378 msec).

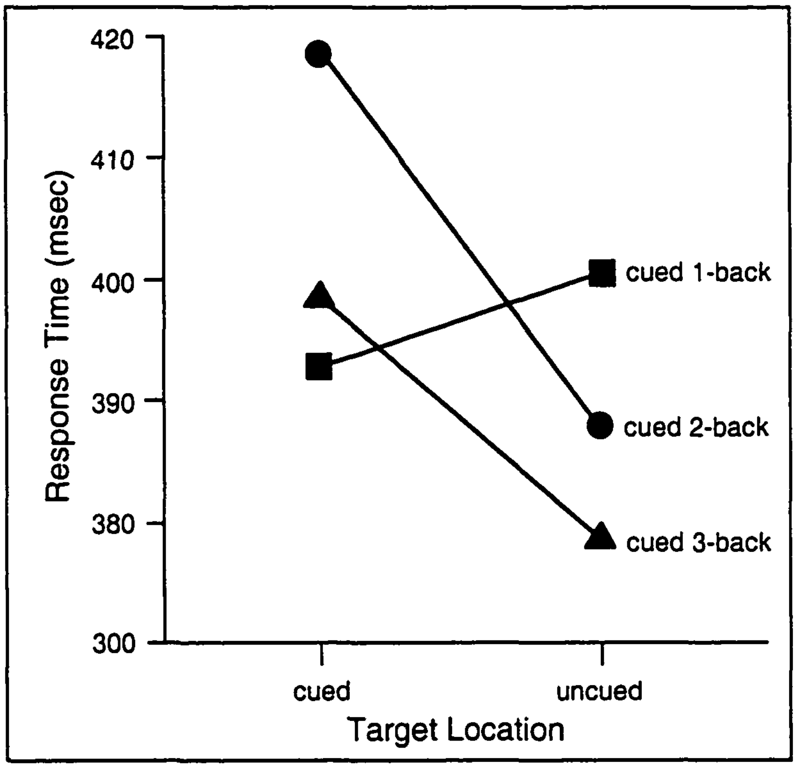

Figure 20. Mean correct RT for cued one-back (one-, two-, and three-cue trials), cued two-back (two- and three-cue trials), and cued three-back (three-cue trials) target locations in Experiment 6.

Response accuracy

As in the previous experiments, mean error rates were low (0.95%). False alarms accounted for the majority of errors (0.9%), with fewer errors occurring as the result of missed responses (0.05%). No anticipatory responses occurred. Error data were analysed as in the previous experiments. Again, there was a significant main effect of trial type, F(9,225) = 2.48, MSe = 0.001, $p < .05$. Importantly, a post-hoc analysis revealed that accuracy did not differ between cued and uncued locations, $F < 1$. Thus, the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

In Experiment 6, evidence was sought that attention is, in fact, committed to cued peripheral locations when multiple IOR occurs. Precisely this result was obtained with the finding that RT was shorter at the most recently cued location (i.e., cued one-back location) than at an uncued location when the cue-target SOA was 100 msec. When a target occurred at a previously cued location with an SOA of 600 msec (i.e., cued two-back location) or 1200 msec (i.e., cued three-back location), characteristic multiple IOR effects were observed. Thus, it can be confidently concluded that attention is committed to the cued location when multiple IOR occurs.

General Discussion

Together the data from the present series of experiments lend strong support to the proposal of Danziger et al. (1998) that multiple IOR is an attentional phenomenon that occurs when attention is committed to multiple onset events. Importantly, it would appear that the occurrence of multiple IOR does not hinge on why attention is committed to different onset events. Rather, the key is whether attention must be committed to different onset events. For instance, multiple IOR is observed if attention is committed to peripheral onsets for the purpose of discriminating cue onsets from target onsets (random session, Experiments 4, 5 and 6) or for the purpose of cue enumeration (blocked session, Experiment 4). But if attention does not need to be committed to peripheral onsets for any reason at all (blocked session, Experiment 5) then multiple IOR is abolished. That attention is committed to the cued peripheral locations when multiple IOR occurs was demonstrated unequivocally in Experiment 6.

IOR at the cued-one back location

If, as argued for the blocked session of Experiment 5, observers are relying on information presented at fixation to prepare for target onset, then why does a small IOR effect occur at a cued one-back location? A strong version of the Danziger et al. (1998) hypothesis would suggest that IOR should be have been totally eliminated in the blocked session.

One possible explanation is that the small one-back IOR effect in the blocked session of Experiment 5 is not an attentional effect. There is strong evidence that an IOR effect can be produced either by attentional orienting or motor activation to the cued location (cf. Klein & Taylor, 1994). According to Klein and Taylor, a peripheral cue may activate a spatially directed detection motor response to the cued location. To avoid responding to the cue, the motor response is inhibited. If a target then appears at the cued location, there is a delay in reactivating the inhibited motor response, and an IOR effect is observed. In support of the Klein and Taylor proposal, Kingstone and Pratt (1999) demonstrated that attentional IOR and motor IOR are separable processes, and that motor IOR can occur whether the onset cue occurs in isolation or in conjunction with the onset of another stimulus (i.e., as was the case in the blocked session of Experiment 5 of the present study). In addition, the motor based account assumes implicitly that activation of one motor response will overwrite the activation of another motor response. Thus, only one motor response can ever be inhibited, and that motor inhibition will be specific to the last location that was cued. This is precisely what was found in the blocked session in Experiment 5, that is, there was only one IOR effect, and it was specific to the most recently cued location.

An alternative account is one that favors some small attentional capture by the peripheral cues in the blocked session in Experiment 5. According to this view, a small amount of attention is drawn to the peripheral cues (a) despite the fact that the onset of the peripheral cues co-occur with the onset of the stimuli at fixation (typically, reflexive attentional capture occurs for onset stimuli that occur in isolation, cf. Yantis, 1996) and (b) despite the fact that participants are presumably focused on the onset stimuli at fixation because the stimuli will indicate when the target is about to occur. Support for the weak attentional capture account comes largely from the finding that the magnitude of the IOR effect at the one-back location in the blocked session of Experiment 5 is much smaller than the IOR effects at the cued one-back location when attention was presumably fully committed to the peripheral cues. that is. the blocked session in Experiment 4, and the random session in Experiments 4 and 5.

Determining whether the IOR effect at the cued one-back location in the blocked session of Experiment 5 is due to motor activation, or to some weak attentional capture by the peripheral cues, is a significant issue for future investigation. It is important to recognize, however, that it is not central to the main question under investigation in the present study. The issue is whether multiple IOR depends on participants having to commit attention to multiple peripheral cues as proposed by Danziger et al. (1998). On this point the present data provide clear and unequivocal evidence in support of Danziger et al. hypothesis. When attention must be committed to the peripheral cues multiple IOR is observed: if it does not need to be committed to the peripheral cues, multiple IOR is not observed. It is interesting to note that this conclusion converges with the main thesis of Tipper et al. (1996), that the establishment of IOR at peripherally cued locations is part of a flexible biological system, and as such whether multiple IOR is established or not is ultimately under the control of the observer. This thesis of course demands that observers be able to control the allocation of attention to peripheral onsets -- which they can -- as demonstrated by Yantis (1996).

Generalizability of the present findings

It is important to note that the present conclusion would appear to apply only to situations in which multiple cued locations cannot be grouped reliably. In a recent study, Abrams and Pratt (1996) found that if multiple cued locations can be grouped together then they can be inhibited together under a single broad "umbrella" of inhibition. That is, what appears to be multiple IOR at several cued locations is merely inhibition of a single broad group of cued location. There is nothing in the present data that questions this conclusion.

Importantly, Abrams and Pratt also reported a third and final experiment in which they found that if the cued locations cannot be grouped together (i.e., the cued locations are not all adjacent) then multiple IOR does not occur. Danziger et al. (1998) demonstrated explicitly that for their paradigm (the paradigm used in the present study) the Abrams and Pratt (1996) conclusion does not apply. That is, Danziger et al. (1998) found that cuing multiple locations that cannot be grouped does produce multiple IOR.

Why the different finding for Danziger et al. (1998) from Abrams and Pratt (1996; Experiment 3)? The data from the present study indicate that the key is whether attention must be committed to the noncontiguous cued locations. When cued locations cannot be grouped (i.e., they are noncontiguous), and attention must be committed to the cued locations (e.g., to discriminate a cue onset from a target onset), then multiple IOR is observed (see Danziger et al., 1998; and the data from the present Experiments 4-6). On the other hand, when the cued locations cannot be grouped and attention does not need to be committed to the cued locations, then multiple IOR is not observed. This was the case in the blocked session in Experiment 5. And it would appear that this is the case for Abrams and Pratt (1996) study. A close examination of their study indicates that in their experiments, observers did not need to attend to the cued locations. On all trials, the central fixation point was always brightened just before a peripheral target appeared. Therefore observers knew that prior to a fixation point being brightened, any peripheral event was a cue and never a target. As a result observers never had to inspect the peripheral cues; hence attention was never committed to the cued locations; and therefore multiple IOR was not observed.

Based on the rationale of Danziger et al. (1998), the hypothesis for the experiments in this chapter was that the generation of IOR at multiple sequentially cued locations depended on attention having to be committed to the cued locations. The results of three experiments support this position: multiple IOR is observed when attention needs to be committed to the noncontiguous cued locations, and it is absent when attention does not need to be committed to the cued locations. This conclusion supports the view of Tipper et al. (1996) that attentional orienting to form IOR at multiple locations is part of a flexible biological system and as such, it is under the control of the observer.

Having demonstrated that IOR can occur at multiple locations and having identified a necessary condition for the generation of multiple IOR, one can ask at how many locations can IOR be held at concurrently? The following study investigated whether there is a limit to the number of locations that can be inhibited in a sequential visual search task. Given that IOR is largest for the most recently cued location and appears to decline for less recently cued locations, it seems likely that there is a finite number of locations that can be inhibited in sequential visual search. Determining this limit is important because it establishes the point beyond which IOR will fail to maximize search efficiency. For instance, if IOR can only co-occur at a maximum of three locations, then when there are more than three locations to be searched, it is reasonable to expect that attention may occasionally return to a previously inspected location.

CHAPTER 5: THE NUMBER OF LOCATIONS THAT CAN BE INHIBITED AND THE FACTORS DETERMINING THE MAGNITUDE OF INHIBITION OF RETURN ACROSS CUED LOCATIONS

Experiments 4, 5, and 6 confirmed the finding of Danziger et al. (1998) that IOR occurs at all cued locations when as many as three locations are cued. The focus of this next investigation is based on the further observation that the magnitude of the IOR effect was not equal across all the cued locations but rather IOR declined from the most recently cued to less recently cued locations. The issues addressed in Chapter 5 include the maximum number of locations at which IOR can be expected to occur (Experiment 7) and the factors that contribute the decline in the magnitude of IOR from the most recently cued location (Experiments 8, 9 and 10).

In Experiment 7, when one through six locations were cued sequentially, IOR effects were measured reliably at five, and possibly, six locations with the magnitude of the IOR effect declining in an approximately linear fashion from the most recently cued location. Experiments 8 and 9 were conducted to determine whether the monotonic decline results from a decay process operating at the inhibited locations and/or whether IOR declines when additional cues are introduced. The results of these experiments clearly demonstrated that the introduction of additional of cues contributes to the monotonic decline of IOR; and suggested that decay may also play a part in this effect. Experiment 10 explored this latter issue and demonstrated unequivocally that temporal decay also plays a role in the linear decline of IOR across cued back locations.

Experiment 7

It is likely that IOR can be held at a limited number of locations at any given point in time. Determining this number is relevant at both a theoretical and paradigmatic level. At a theoretical level, it is important to establish the boundary condition beyond which

IOR can no longer be expected to improve search efficiency. For instance, if IOR can co-occur at no more than three locations, then when there are more than three locations to be searched, it is reasonable to expect that attention will begin to return to a previously inspected location. At a paradigmatic level, it is important in designing appropriate paradigms for investigating multiple IOR. The aim of this experiment was to determine the number of locations at which IOR can be measured in a sequential visual search task. The sequential cuing paradigm used in Experiment 6 was modified by increasing the number of possible target locations from five to eight, and doubling the number of possible cues from three to six.

Method

Participants

Thirty undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Stimuli and Procedure

Stimuli were identical to Experiment 6 with eight, rather than five, dark-gray outline placeholders placed equidistantly around an imaginary circle with a radius of 6.5° va. The first placeholder was located at an angle of 22.5° to the right of the vertical meridian and the last placeholder was located at an angle of 22.5° to the left of the vertical meridian.

Cue durations were 100 msec. The target remained present until a response was recorded or 1500 msec had elapsed, whichever occurred first. The intertrial interval was 1000 msec. The SOA between all stimuli (cues and target) was fixed at 500 msec across trials.

Each trial began with a 100 msec warning tone. Following a 500 msec SOA either a target appeared or a placeholder was cued for 100 msec. If a placeholder was cued, there was a 500 msec SOA and then a target appeared or a different placeholder was cued. Up to six placeholders could be cued prior to target onset, with the SOA between all stimuli (cues and target) fixed at 500 msec. On catch trials, seven cues appeared and no target was presented.

Design

Observers participated in two 50 minute sessions separated by two or three days. Each session consisted of 600 trials divided into 12 blocks of 50 trials. Thus, each participant received a total of 1200 test trials. Of these 1200 trials, 24 were zero-cue trials (the target appeared following the warning tone) and 24 were catch trials (the target never occurred). The remaining 1152 trials were divided equally among the six peripheral cue conditions (i.e., one-cue, two-cue, three-cue, four-cue, five-cue, and six-cue trials) resulting in 192 trials per cue condition. Each block of trials contained one zero-cue trial and one catch trial. On trials when one location was cued prior to target onset (i.e., on one-cue trials), the target would appear 24 times at the cued location and 24 times at each of the seven uncued locations. Similarly, for the six-cue trials the target would appear 24 times at each of the six cued locations and 24 times at each of the two uncued locations.

For each of the two test sessions, participants first received 10 practice trials. All trials were terminated when a keypress response was executed or 1500 msec after the last cue event, whichever came first.

Results

Separate repeated measures ANOVAs were performed for each of the cued-back locations (one-back through to six-back). For one-back through five-back location trials, a two-factor ANOVA was conducted with location (cued n-back vs. uncued) and number of cues as factors. For the six-back location trials, a one-factor ANOVA was conducted with target location (six-back vs. uncued) as a factor. Mean correct RT as a function of target location is presented in Table 1. Mean IOR effect (cued - uncued RT) as a function of target location are presented in Table 1 and Figure 21.

Cued one-back trials

The main effects of target location, $F(1,29) = 64.84$, $MSe = 317.59$, $p < .001$, and number of cues, $F(5,145) = 99.09$, $MSe = 295.31$, $p < .001$, were significant. The main effect of target location indicated that IOR was present. The effect of number of cue indicated the presence of the previously described warning signal effect. A significant interaction between target location and number of cues was not observed, $F(5,145) = 1.44$, $MSe = 185.29$, $p > .2$, indicating that the IOR effect did not vary as a function of the number of cues.

Cued two-back trials

Again, the main effects of target location (i.e., IOR), $F(1,29) = 54.99$, $MSe = 171.05$, $p < .001$, and number of cues (i.e., warning signal effect), $F(4,116) = 48.16$, $MSe = 229.58$, $p < .001$, were significant. No significant interaction between target location and number of cues was observed, $F < 1$.

Cued three-back trials

Significant main effects were found for target location, $F(1,29) = 23.48$, $MSe = 145.31$, $p < .001$, and number of cues, $F(3,87) = 48.16$, $MSe = 174.49$, $p < .001$. A significant interaction between target location and number of cues was observed, $F(3,87) = 2.86$, $MSe = 136.23$, $p < .05$. Post-hoc comparisons revealed the source of the interaction: a significant IOR effect at the three-back location when five or six cues preceded target onset, F(1, 87) = 18.78 and 11.02, respectively; all ps < .01, but only a marginally significant IOR effect on three-cue trials, F(1, 87) = 3.60, MSe = 136.23, p < .07, and a nonsignificant IOR effect on four-cue trials, F < 1. Because a target location x number of cues interaction is not observed at any other cued back location, the importance of the present interaction is not readily apparent, and will not be considered further.

Table 1. Mean Correct RT (msec) and Mean IOR Effect (msec) for Target Location as a function of Number of Cues for Experiment 7.

Target Location	Number of Cues												Mean IOR Effect
	1		2		3		4		5		6		
	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	
uncued	432		408		394		383		373		374		
1-back	441	9	429	21	410	17	396	13	390	17	388	14	15
2-back			417	10	402	8	393	10	389	16	385	11	11
3-back					399	6	384	1	386	13	384	10	8
4-back							388	5	379	7	381	7	7
5-back									382	9	379	5	7
6-back											376		2

Note. For each target location, IOR effects were based on the mean cued RT minus the mean uncued RT across the same number of cues.

Cued four-back trials

Main effects of target location, F(1,29) = 14.77, MSe = 128.84, p < .001, and number of cues, F(2,58) = 10.11, MSe = 145.27, p < .001, were again significant. No significant interaction between target location and number of cues was observed, F < 1.

Cued five-back trials

A significant main effect was observed for target location, F(1,29) = 9.64, MSe = 160.27, p < .01. No significant main effect was observed for number of cues, F < 1, indicating that participants were maximally prepared to respond to the target. No significant interaction between target location and number of cues was observed, F < 1.

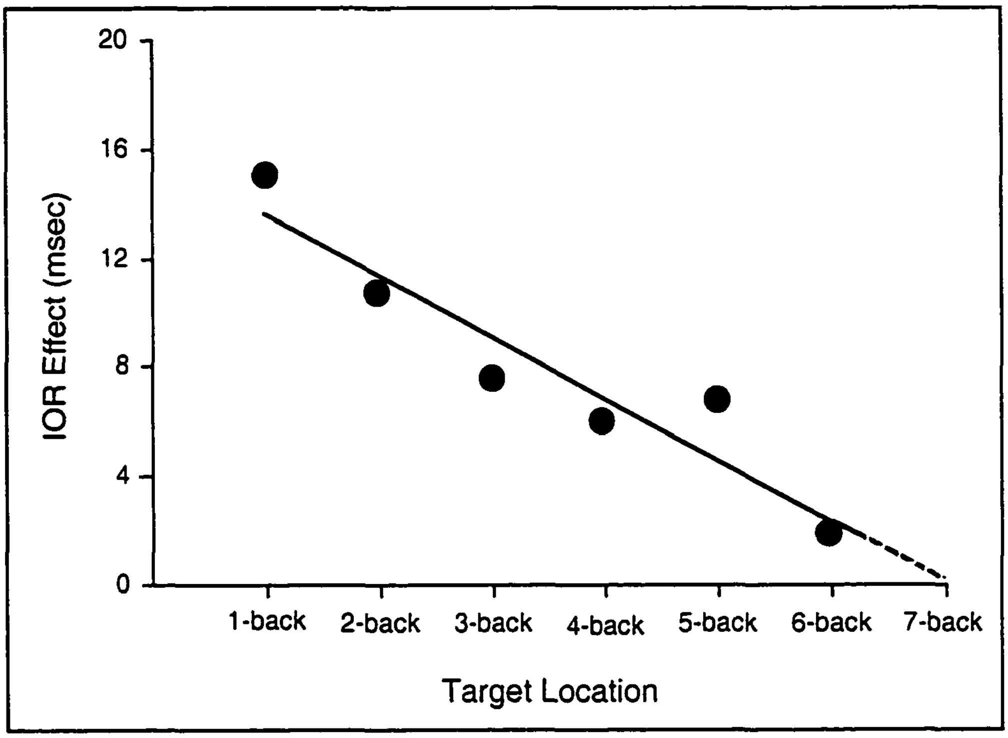

Figure 21. IOR effects (msec) (cued RT minus uncued RT) for cued one-back through six-back locations used in the regression analysis. The y-intercept is 15.9 msec and the slope across cued back locations is -2.3 msec. The regression line has been extrapolated (slashed line) to reveal the hypothetical location (cued seven-back) where the IOR effect would reach zero msec.

Cued six-back trials

No significant main effect was observed for target location, F < 1, indicating that an IOR effect was not present.

Response accuracy

Overall error rates were consistently low (0.9%). False alarms occurred on 0.6% of all the trials; misses occurred on 0.2% of trials; anticipations occurred on less than 0.1% of the trials. Error data were analysed with a one-factor repeated measures ANOVA with trial type (one-cue cued one-back, one-cue uncued, two-cue cued one-back, etc. and no target - catch trials). ANOVA revealed that the error rates differed significantly from each other, $F(28,812) = 3.47$, $MSe = .0004$, $p < .001$. However, a post-hoc comparison showed that errors did not vary as a function of whether a target appeared at a cued versus an uncued location, $F(1,812) = 1.54$, $MSe = .0004$, $p > .2$, reflecting that the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

In summary, IOR effects were observed at the cued one-back through five-back locations (ranging from 15 msec to seven msec; see Table 1). Furthermore, the IOR effect declined fairly linearly from the most recently cued location to the least recently cued location. This decline could represent a simple decay process of the inhibitory tags with the decay occurring at an exponential rate asymptotically approaching zero msec.

However, it is also plausible that the two msec IOR effect at the six-back location is also real. In the limited range of cued back locations examined in this experiment, a linear fit of the IOR effect can also be performed. When a linear regression analysis of the IOR effects reported above (see Figure 21) was conducted, target location accounted for 89.5% of the IOR variance, $F(1, 4) = 34.26$, $MSe = 2.60$, $p < .01$.

The slope of this linear regression line was -2.3 msec, indicating that the IOR effect decreased by about 2.3 msec per location. Given that the decline in IOR across locations is approximately linear, one can predict the size of the IOR effect at the six-back location from the slope (-2.3 msec) and intercept (15.9 msec) of the regression line, 15.9 msec - (2.3 msec x 6) = 2.1 msec. This predicted IOR effect of 2.1 msec at the six-back location matches remarkably well with the two msec effect that was observed, so it is reasonable to consider that the two msec effect is real.

The results from Experiment 7 demonstrated that in a sequential cuing paradigm, the magnitude of the IOR effect declines linearly from the most recently cued location and that IOR can be found reliably at five, possibly six locations. This finding leads to the question of what might be underlying the decline of IOR. There are several accounts that can explain the monotonic decline of IOR.

One possibility is that the IOR effect may simply decay with time. As locations are searched, they are tagged with inhibition and as time passes, each inhibitory tag fades at some constant rate.

A second possibility is that the monotonic decrease in IOR is due to the addition of cued locations. For instance, when a location is cued, it is assigned an inhibitory value (e.g., I_1) and is entered into a queue of inhibited locations. A location that has been assigned an inhibitory value will undergo a reduction in attentional priority such that it will be attended/inspected only after locations that have an inhibitory values of zero have been attended/inspected. When a second location is cued, it too is assigned an inhibitory value (e.g., I_2) and is entered into the queue. This process can be repeated until the limited number of positions within the queue is filled.

There are at least two ways that inhibitory values can be assigned to the locations entered into the queue. In the first model, when a location is cued, it is assigned a large inhibitory value (I_1) and enters into Position 1 of the queue. When a second location is cued, it is assigned the same inhibitory value as the first cued location (i.e., I_1) and is entered into the Position 1 in the queue, causing the previously cued location to move to Position 2 of the queue. As the first cued location moves into Position 2 of the queue, it has an associated loss of inhibition and its inhibitory value is reduced (e.g., I_1-x). When a third location is cued, it is assigned a large inhibitory value (I_1) and is entered into Position 1 in the queue, causing the second cued location to move to Position 2 of the queue and a reduction in its inhibitory value (I_1-x). The first cued location now moves into Position 3 and has an even lower inhibitory value (I_1-2x). In this model, which will be referred to as the priority queue A hypothesis, the cued location that has entered into the queue the most recently has the greatest amount of inhibition. Its position in the queue and its inhibition is systematically reduced with each additional cued location entering the queue.

There is another way that a priority queue model, which will be referred to as priority queue B hypothesis could work. Rather than the first cued location being assigned a large inhibitory value, it is assigned a small inhibitory value. It is entered into Position 5 in the queue. When a second location is cued, it is assigned a larger inhibitory value (e.g., I_1+x) and is entered into Position 4 in the queue. When a third location is cued, it is assigned an even larger inhibitory value (e.g., I_1+2x) and is entered into Position 3 in the queue and so on until the five positions in the queue have been filled. It is reasonable to consider that the inhibitory tags undergo decay. (For instance, if a target was missed and its location was inhibited, it is reasonable that at some point the location would be re-examined.) At this point, the first cued location will have lost its associated inhibitory value and the cued locations would be shifted downward (i.e., the cued location originally at Position 4 would now occupy Position 5. In this model, then, positions within the queue do not undergo any changes until the capacity limit of the queue has been reached.

This argument has a certain appeal. In most IOR paradigms, the nontargets are identical. If IOR is part of a flexible biological system, then it is reasonable that some small amount of IOR would be required to inhibit a single cued location, leaving equal access to the uncued or uninhibited locations. When the next location is cued, a larger amount of IOR is required to "push" it below the inhibitory value of the first location and so on. The elegance of such a system would be that the priority queue is still established but the return of attention to a previously examined location could occur more quickly when only one location has been inhibited.

The outcome of the two models is the same when the queue has been filled with the most recently cued location having the most inhibition, the second most recently cued location having less inhibition and so on. The difference between the models is the magnitude of inhibition associated with each cued location before the queue is filled. The results of the present experiment offer support for the priority queue B hypothesis as IOR is roughly equivalent at the first location cued in the trial sequence, regardless of the number of additional cues that follow the initial cue. Specifically, IOR was 9 msec at a cued one-back location on a one-cue trial, 10 msec at a cued two-back location on a two-cue trial, 6 msec at a cued three-back location on a three-cue trial, 5 msec at a cued four-back location on a four-cue trial, 9 msec at a cued five-back location on a five-cue trial, and 2 msec at a cued six-back location on a six-cue trial). Conversely, the results of the present experiment do not appear to support the priority queue A hypothesis as IOR was not equal across cued one-back locations as is suggested by this hypothesis. Specifically, at a cued one-back location IOR was 9 msec on a one-cue trial, 21 msec on a two-cue trial, 17 msec on a three-cue trial, 13 msec on a four-cue trial, 17 msec on a five-cue trial, and 14 msec on a six-cue trial). However, these differences in IOR effects are not strong enough to allow for a reliable conclusion as to which hypothesis best accounts for the results.

A third possibility is that the monotonic decline in IOR results from both decay and the addition of cued locations where the inhibitory tags are applied in an all-or-none fashion. For instance, if, as suggested by Pylyshyn's (1989) FINST theory, there are a limited number of spatial tags available, then a linear decline in IOR across cued back locations will occur when all of the tags have been used. That is, a decline in IOR should begin to occur only after the fourth or fifth location has been cued. However, if it is assumed that locations tagged with inhibition early in a cue sequence are increasingly more likely to have their tags stolen (interference) or lost (temporal decay and/or interference) as additional cues are presented, then a linear effect could be observed (see Schmidt, Fisher, & Pylyshyn, 1998).

Experiment 7 does not determine whether the monotonic function of IOR across cued locations is due to the effects of cuing additional locations or the passage of time. It is therefore imperative that both, the effects of temporal decay and the addition of cues, be studied to determine what contribution each mechanism makes to the observed linear decline in IOR across cued locations. Determining whether a decay process or inhibitory priority queue mechanism produces the decrease in IOR across cued locations can be determined in the following way. The role of temporal decay can be tested by fixing the number of cues that occur before the target while varying the time interval between the first cue and target onset. In Experiment 8, six cues occur prior to target onset while the cue-cue and cue-target SOAs on a single trial vary. The role of additional cues can be tested by fixing the time interval between the first cue and target onset while varying the number of cues. In Experiment 9, one to six cues occur prior to target onset with the initial cue-target SOA fixed across trials.

Experiment 8

The temporal decay hypothesis was tested by holding the number of cues preceding target onset constant while varying the SOA between cues and the target. A 300 msec SOA was chosen as the starting point because the IOR literature supports the idea that, for detection tasks, IOR effects are evident by 300 msec. If the IOR effect decays with time then it would be expected that as SOA increases, IOR effects should become smaller at each of the cued locations.

Method

Participants

Fifty undergraduates participated for course credit. Two participants were replaced because of high error rates (> 20%). All reported normal or corrected-to-normal vision.

Stimuli and Procedure

The stimulus display was exactly as used in Experiment 7 with the following exceptions. The eight dark-gray outline placeholders were situated around an imaginary circle having a radius of 7.0°. Cue durations were 200 msec. The SOA between all stimuli (cues and target) were fixed for a single trial but varied across trials at 300, 400, 500, 600, 700 and 800 msec. Six cues always appeared prior to target onset but the SOAs between stimuli varied from trial to trial. Each trial began with a 100 msec warning tone. Five hundred milliseconds following the onset of the warning tone, a placeholder was cued, followed by the sequential cuing of five different placeholders at a constant SOA. Catch trials (i.e., no target appeared) occurred after six cues for each SOA. An experimental session lasted approximately 80 minutes.

Design

Participants received 25 practice trials followed by 12 blocks of 54 test trials, for a total of 648 test trials. The 648 test trials consisted of 108 trials at each SOA (300, 400, 500, 600, 700, 800 msec). Of the 108 trials, there were 12 trials where the target appeared at each of the six cued locations, 12 trials where the target appeared at each of the two uncued locations, plus 12 catch trials where no target was presented

Results

A two-factor repeated measures ANOVA was conducted with target location (cued one-, two-, three-, four-, five-, six-back, uncued) and SOA (300, 400, 500, 600 700, 800 msec) as factors. Mean correct RT as a function of target location and SOA is presented in Table 2. Mean IOR effect as a function of target location and SOA is presented in Table 2 and Figure 22.

Table 2. Mean Correct RT (msec) and Mean IOR Effect (msec) for Target Location as a function of SOA in Experiment 8.

Target Location	SOA												Mean IOR Effect
	300		400		500		600		700		800		
	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	
uncued	407		389		392		390		394		394		
1-back	411	4	402	13	412	20	415	25	415	21	415	21	17
2-back	411	4	408	19	410	18	409	18	413	19	406	13	15
3-back	409	1	388	0	403	11	405	14	408	14	399	5	8
4-back	406	0	389	0	395	3	396	6	400	5	397	3	3
5-back	405	0	404	15	400	8	399	9	397	3	395	0	6
6-back	411	4	393	0	395	3	398	8	393	0	396	2	3

The main effect of target location was significant, F(6,294) = 17.45, MSe = 736.63, p <.001. Planned contrasts of this effect revealed a significant IOR effect (longer RT at a cued than at an uncued) for one-back, two-back, three-, and five-back locations (all Fs > 6.21, all ps < .05) but not for a four-back location, F(1,294) = 1.53, MSe = 736.63, p > .2, or a six-back location, F(1,294) = 1.98, MSe = 736.63, p >.1. The interaction between target location and SOA was not significant, F(30,1470) = 1.413, MSe = 672.74, p <.07, suggesting that IOR does not decay.

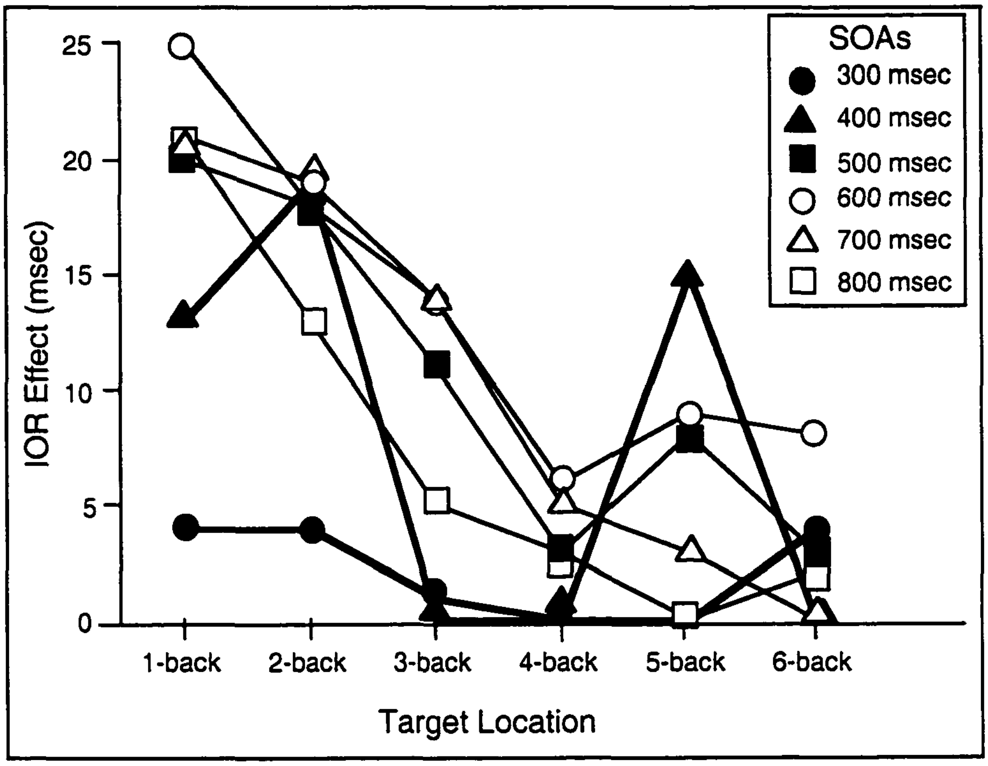

Figure 22. IOR effects (msec) as a function of target location and SOA. The thickened lines demonstrate the unstable IOR effects for 300 and 400 msec SOA trials in Experiment 8.

Response accuracy

As in Experiment 7, overall mean error rates were consistently low (1.14%). False alarms accounted for the majority of the errors (0.91%) with misses and anticipations accounting for fewer errors (0.13% and 0.10% , respectively). Error analysis was conducted as in Experiment 7. Error data were analysed as in Experiment 7. The ANOVA revealed that the error rates did not vary as a function of target location or SOA, F(47,2303) = 1.29, MSe = .001, p > .09.

Discussion

Experiment 8 tested the decay hypothesis which suggests that the monotonic function of multiple IOR results from the temporal decay of the inhibitory tags. This hypothesis was tested by holding the number of cues constant while varying the cue-cue and cue-target SOA. If IOR decays, the expected result would be that IOR at a cued back location would decrease as SOA increased. The absence of an interaction between target location and SOA is indicative that the IOR effect does not undergo temporal decay.

A closer examination of Table 2 and Figure 22 reveals several interesting findings, including one which cautions against accepting this conclusion without further investigation. The first finding is that at SOAs of 300 and 400 msec, IOR effects were small and did not demonstrate the characteristic monotonic decline. At a 300 msec SOA, IOR effects were 4, 4, 1, 0, 0, and 4 msec for cued one-, two-, three-, four-, five-, and six-back locations, respectively and non-monotonic. At a 400 msec SOA, IOR effects were substantially stronger with an effect of 13, 18, 0, 0, 15, 0 msec for cued one-, two-, three-, four-, five-, and six-back locations, respectively, although the characteristic monotonic function had not yet appeared. Thus, it appears that for multiple location IOR, an SOA of longer than 400 msec is required to obtain both a strong IOR effect at each cued location and the characteristic monotonic function across cued back locations. This result is interesting as it contrasts with single location IOR studies where IOR develops rapidly at SOAs of 300 msec (e.g., Posner & Cohen, 1984; Maylor, 1985). Multiple location IOR appears to have a somewhat different time course than does single location IOR. The absence of an interaction between target location and SOA may simply reflect a lack of power in the ANOVA due to the atypical results found for the 300 and 400 msec SOA conditions.

A second interesting finding is that IOR in the 800 msec SOA condition appears to decline more rapidly than in the 500, 600, and 700 SOA conditions. Although IOR at a cued one-back location was relatively stable for the 500 through 800 msec SOA conditions (20, 25, 21, and 21 msec, respectively) the decline thereafter was more rapid for the 800 msec SOA (13, 5, 3, 0 , and 2 msec for the two- to five-back locations, respectively) than for the 500, 600, and 700 msec SOAs (18, 18, and 19 msec for a two-back; 11, 14, and 14 msec for a three-back; 3, 6, and 5 msec for a four-back; 8, 9, and 3 msec for a five-back location, respectively). This difference in the rate of decline in the 800 msec SOA condition could reflect the decay of IOR. The possibility that IOR undergoes temporal decay must be tested further since eliminating the 300 and 400 msec SOA conditions from the general pattern of results substantially weakens the power of the ANOVA.

A third finding in this experiment is the confirmation that as in Experiment 7, IOR can occur concurrently at a minimum of up to five locations.

From the present experiment, it can be concluded that (a) SOAs of 500 msec are required to realize robust multiple IOR effects, (b) temporal decay has not been ruled out as a process underlying the monotonic function of multiple IOR, and (c) IOR can be reliably observed at five locations in a sequential cuing paradigm. Experiment 9 examines the effect of the addition of cued locations on the characteristic monotonic function of multiple IOR by holding time constant and varying the number of cues that occur in that time frame.

Experiment 9

In Experiment 9, the role played by additional cues in the decline of IOR was tested by holding the time interval between the first cue and the appearance of the target constant while varying the number of cues that occurred between the initial cue and the target. In Experiment 9, one-, two-, three-, four- five-, and six-cue trials occurred equally often but the interval between the initial cue and the target was constant at 3000 msec. Two accounts of how the addition of cued locations could affect the monotonic function of IOR have been proposed. The priority queue A account suggests that the IOR effect at an inhibited location undergoes a reduction in IOR because its inhibitory value is reduced (i.e., lower inhibitory priority). According to the priority queue A hypothesis, then, IOR effects should be largest for the most recently cued location (i.e., a one-back location) regardless of the number of cues occurring on a trial because that location has the largest amount of IOR (i.e.. maximum inhibitory priority). The priority queue B account suggests that IOR at a cued location increases as a function of the number of additional cued locations. According to the priority queue B hypothesis, then, IOR will be at an equal baseline level for the initial cue (i.e., at a one-back location on a one-cue trials and at a six-back location on a six-cue trial) and increase for each subsequently cued location. It is important to note that the priority queue A account assumes that decay does not play a role whereas the priority queue B account assumes that decay does not play a role in the decline of IOR across cued back locations only until the queue has been filled.

Method

Participants

Fifty undergraduates participated for course credit. Two participants were replaced because of high error rates (> 20%). All reported normal or corrected-to-normal vision.

Stimuli and Procedure

The stimulus display was the same as in Experiment 8 with the following exceptions. One through to six cues appear equally often prior to target onset and the

SOAs between the cues and the target varied as a function of the number of cues. The SOA from the first cue to the target was fixed at 3000 msec. Thus, on a one-cue trial, the cue-target SOA was 3000 msec. On a two-cue trial, the cue-cue and final cue-target SOAs were 1500 msec. On a three-cue trial they were 1000 msec, on a four-cue trial they were 750 msec, on a five-cue trial they were 600 msec, and on a six-cue trial they were 500 msec. Catch trials (i.e., no target appeared) occurred after one, two, three, four, five, and six cues. An experimental session lasted approximately 80 minutes.

Design

Participants received 25 practice trials followed by 12 blocks of 54 test trials, for a total of 648 test trials. The 648 test trials were divided equally among the one-, two-, three-, four-, five-, and six-cue conditions resulting in 108 trials per cue condition. Since the target was equally likely to appear at any of the eight locations, for one-cue trials, there were 12 cued trials, 84 uncued trials, and 12 catch trials. Similarly, for two-cue trials, there were 24 cued trials (i.e., 12 at each of the two cued locations), 72 uncued trials, and 12 catch trials and so on for the remaining cue conditions[4].

Results

Data analyses were conducted exactly as in Experiment 7 with separate repeated measures ANOVAs for each target location. Mean correct RT as a function of target location and number of cues/SOA is presented in Table 3. Mean IOR effect as a function of target location and number of cues/SOA is presented in Table 3 and Figure 23.

---

[4] Due to a programming error, there were no catch trials for the six-cue condition. In addition, three rather than two uncued trials occurred in each block of trials for this condition. However, participants did not appear to notice the absence of the catch trial or the occurrence of the additional uncued trial since RT was not any shorter for the uncued trials in this condition relative to the uncued trials in the other cue conditions.

Cued one-back trials

The main effects of target location, F(1,49) = 102.95, MSe = 669.24, p < .001, and number of cues, F(5,245) = 2.57, MSe = 908.97, p < .05, were significant. The main effect of target location indicates the presence of IOR with longer RT at a cued location (425 msec) than at an uncued location (404 msec). The effect of number of cues indicated the presence of a compound warning signal effect that shows participants were better prepared to respond to a target as the number of cues increased *and* as the SOA between stimuli decreased. RT was stable across the first four cues (417, 419, 416, 418 msec; see Table 3, rows uncued and one-back) and then decreased for five and six cues (410, 407 msec).

Table 3. Mean Correct RT (msec) and Mean IOR Effect (msec) for Target Location as a function of SOA in Experiment 9.

Target Location	Number of Cues (SOA)												Mean IOR Effect
	1 (3000)		2 (1500)		3 (1000)		4 (750)		5 (600)		6 (500)		
	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	
uncued	414		410		405		401		395		397		
1-back	419	5	428	17	427	21	436	35	425	31	417	20	21
2-back			421	10	416	11	420	19	422	27	413	16	17
3-back					416	11	414	12	408	14	403	6	11
4-back							410	9	404	9	406	9	9
5-back									402	7	397	0	3
6-back											406	9	9

A significant interaction between target location and number of cues was also observed, F(5,245) = 6.05, MSe = 466.57, p < .001, indicating that the IOR effect varied as a function of the number of cues (5, 17, 21, 35, 31, and 20 msec for one-, two, three-, four-, five-, and six-cue trials, respectively).

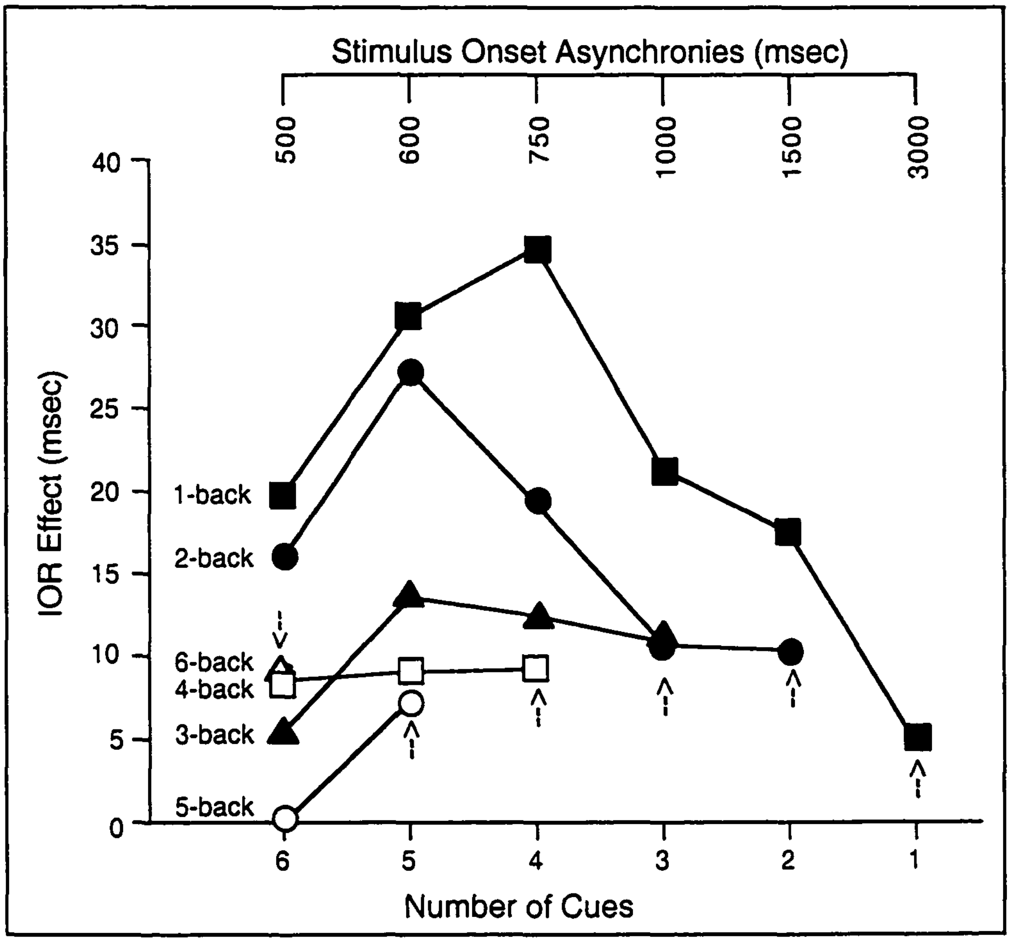

Figure 23. Mean IOR effect (msec) as a function of number of cues/SOA and cued back location. The arrows indicate the first location cued (i.e., cue-target SOA is 3000 msec for all of these locations) in Experiment 9.

Cued two-back trials

The main effect of target location, F(1,49) = 71.61, MSe = 488.83, p < .001, was significant, indicating the presence of IOR (i.e., RT of 419 and 402 msec at a cued and an uncued location, respectively). Neither the main effect of number of cues, F(4,196) = 1.75, MSe = 789.93, p > .1, nor the interaction between target location and number of cues F(4,196) = 1.76, MSe = 696.99, p > .1, were significant, indicating that the IOR effect did not vary as a function of the number of cues (10, 11, 19, 27, and 16 msec for two, three-, four-, five-, and six-cue trials, respectively).

Cued three-back trials

The main effect of target location, F(1,49) = 15.23, MSe = 728.84, p < .001, was significant, indicating the presence of IOR (i.e., RT of 410 and 400 msec at a cued and an uncued location, respectively). The main effect of number of cues was significant, F(3,147) = 4.17, MSe = 598.53, p < .05, reflecting a decreasing in RT as the number of cues increased (410, 407, 401, and 400 msec for three, four, five, and six cues, respectively). The interaction between target location and number of cues was not significant, F < 1, indicating that the IOR did not vary as a function of the number of cues (11, 12, 14, and 6 msec for three-, four-, five-, and six-cue trials, respectively).

Cued four-back trials

The main effect of target location, F(1,49) = 13.96, MSe = 426.11, p < .001, was significant, indicating the presence of IOR (i.e., RT of 407 and 398 msec at a cued and an uncued location, respectively). Neither the main effect of number of cues, F(2,98) = 1.63, MSe = 675.14, p > .2, nor the interaction between target location and number of cues, F < 1, was significant. Hence, IOR did not vary as a function of the number of cues (9 msec for three-, four-, five-, and six-cue trials).

Cued five-back trials

Neither the main effects of target location, F(1,49) = 1.49, MSe = 347.15, p > .2, nor number of cues, F < 1, nor the interaction between target location and number of cues, F(1,49) = 1.33, MSe = 599.11, p > .2, was significant. These results suggest that the IOR effect of 7 msec for five-cue trials is not real.

Cued six-back trials

The main effect of target location was not significant, F(1,49) = 3.22, MSe = 625.239, p < .08, indicating that the 9 msec IOR effect at a 4800 msec SOA is most likely not real.

Response accuracy

Again, overall mean error rates were consistently low (1.42%). False alarms accounted for the majority of the errors (0.94%) with misses and anticipations accounting for fewer errors (0.10% and 0.47% , respectively). Error data was analysed as in Experiments 7 and 8. The ANOVA revealed that the error rates differed significantly from each other, F(31,1519) = 1.81, MSe = .001, p < .01. A post-hoc comparison revealed that errors did not vary as a function of whether a target appeared at a cued versus an uncued location, F < 1.

Discussion

There are several notable findings in this experiment. First, an examination of Figure 23 reveals that the IOR effects are strongest at an SOA of between 600 and 750 msec. Furthermore, the monotonic decline is well-established at all but the 500 msec SOA, indicating that this SOA is probably too fast to allow the full development and orderly decline of IOR.

Second, the addition of cues appears to be responsible for the monotonic function of multiple IOR in the manner predicted by the priority queue B hypothesis. The prediction here was that a baseline level of IOR should be observed at the initially cued location with IOR increasing as a function of each additional cue. That is, the IOR effect should be constant for a cued one-back location on one-cue trials, at a cued two-back location on two-cue trials, at a cued three-back location on three-cue trials, and so on.

This is exactly the pattern of results seen in this experiment. At a 3000 msec SOA, IOR effects are relatively stable at five to 10 msec, regardless of the number of cues that have intervened (i.e., IOR was 5 msec at a cued one-back location on a one-cue trial, 10 msec at a cued two-back location on a two-cue trial, 11 msec at a cued three-back location on a three-cue trial, 9 msec at a cued four-back location on a four-cue trial, 7 msec at a cued five-back location on a five-cue trial, and 9 msec at a cued six-back location on a six-cue trial). Thus, Experiment 9 supports the hypothesis that increasing the number of cued locations increases the magnitude of IOR for each additional cued location. In contrast, the priority queue A hypothesis predicted that most recently cued locations should have the highest inhibitory value (i.e., the lowest priority) as they have entered the queue most recently. The results of this experiment do not support this hypothesis as IOR effects are not equal for cued one-back locations (i.e., at a cued one-back location IOR was 5, 17, 21, 35, 31, and 20 msec for one-, two- three-, four-, five-, and six-cue trials, respectively). This argument is supported further by the significant interaction between target location x number of cues/SOA which demonstrates that IOR was not equivalent across cued one-back locations.

It is important to note that acceptance of the priority queue B hypothesis relies on the assumption that IOR does not undergo any temporal decay before the queue capacity has been reached. Recall that in Experiment 8, although the lack of a significant interaction between target location and SOA suggested that the linear function of IOR reflects <u>only</u> the addition of cues and <u>not</u> a decay process, it was not possible to rule out the possibility that decay occurred at an 800 msec SOA. Therefore, the conclusion that only the priority queue B hypothesis accounts for the monotonic function of IOR cannot be accepted without further testing.

Third, although IOR was statistically significant for the cued one-back to four-back locations, it can be concluded that IOR effects are found at up to five cued back locations. Recall, that in Experiment 7, the absence of an IOR effect at the five- and six-back locations must be interpreted with caution because of the experimental design. It was argued that the nature of the design requires that equal number of one through six-cue trials occur. Therefore, there are fewer trials contributing to the cued five- and six-back locations than to the one- to four-back locations. An inspection of Table 3 and Figure 23 suggest that the data for the five- and six-back locations on six-cue trials should be considered with caution because the data appear to be fairly "noisy". The same conservative approach does not necessarily hold for the cued five-back location on a five cue trial as longer SOAs were used on those trials. At this SOA, IOR appears to be well established with the magnitude declining in an approximately linear manner across cued back locations. Thus, it is reasonable to conclude that the present experiment lends support to the findings in Experiments 7 and 8 that IOR occurs reliably at a minimum of five locations.

From Experiment 9, it can be concluded that (a) IOR effects decline after SOAs of up to 750 msec although SOAs of 500 msec are sufficient to realize the monotonic function of IOR across cued back locations, (b) the IOR effect increases with the addition of cued locations assuming that IOR does not decay before the inhibitory queue is filled, and (c) IOR can be reliably observed at five locations in a sequential cuing paradigm.

Before concluding that the addition of cued locations is the only critical factor underlying the monotonic function of IOR, decay of the IOR effect must be eliminated as a factor contributing to the linear decline. Experiment 10 is a final test of the decay hypothesis.

Experiment 10

The results from Experiments 8 and 9 suggested that the monotonic function of IOR reflects the addition of cues rather than a temporal decay. However, in the 800 msec

SOA condition in Experiment 8, IOR appeared to be declining at a faster rate than in the 500 to 700 msec SOA conditions. It could be the case that the observation of a decay process requires an SOA of 800 msec or greater. In Experiment 10, a more comprehensive assessment of the whether the monotonic function of IOR arises from a decay process and/or the addition of cued locations was undertaken. The key manipulation in this experiment was the systematic variation of the final cue-target SOAs ranging from 500 to 3000 msec.

Method

Participants

Fifty undergraduates participated for course credit. Six participants were replaced because of high error rates (> 20%). All reported normal or corrected-to-normal vision.

Stimuli and Procedure

The stimulus display was the same as in Experiment 9 with the following exceptions. Five placeholders surrounded the central fixation stimulus. One to three placeholders could be cued prior to target onset. For all cue conditions, the target was equally likely to appear at an SOA of 500, 1000, 1500, 2000, 2500, or 3000 msec from the onset of the final cue. Thus, on one-cue trials, the target was equally likely to appear at an SOA of 500, 1000, 1500, 2000, 2500, or 3000 msec. On a two-cue trial, the target was equally likely to appear at an SOA of 500, 1000, 1500, 2000, 2500, or 3000 msec from the onset of the second cue, or at an SOA of 1000, 1500, 2000, 2500, 3000, or 3500 msec from the onset of the first cue and so on. On two- and three-cue trials, the cue-cue SOA was 500 msec. Catch trials (i.e., no target appeared) occurred after one, two, or three cues.

Design

Observers participated in two 55 minute sessions on consecutive days. Each session consisted of 576 trials divided into 6 blocks of 96 trials. Thus, each participant received a total of 1152 test trials. Of these 1152 trials, 72 were catch trials (i.e., no target occurred) distributed equally among one-, two-, and three-cue trials. The remaining 1080 trials were divided equally among the three cue conditions (i.e., one-, two-, and three-cue trials) resulting in 360 trials per cue condition. Of these 360 trials, 60 trials occurred for each final cue-target SOA (i.e., 500, 1000, 1500, 2000, 2500, 3000 msec). Of theses 60 trials, on one-cue trials, the target would appear 12 times at the cued location and 12 times at each of the four uncued locations. Similarly, for the three-cue trials the target would appear 12 times at each of the three cued locations and 12 times at each of the two uncued locations. Participants received 25 practice trials before each of the two test sessions.

Results

Separate repeated measures ANOVAs were performed for each of the cued back locations (one-back through to three-back). For one-back and two-back location trials, a three-factor ANOVA was conducted with target location (cued n-back vs. uncued), number of cues, and SOA as factors. For the three-back location trials, a two-factor ANOVA was conducted with target location (three-back vs. uncued) and SOA as a factor. Mean correct RT as a function of target location is presented in Table 4. Mean IOR effect (cued - uncued RT) as a function of SOA and number of cues for each cued back location are presented in Table 4 and Figures 24, 25, and 26 for one-, two-, and three-cue trials, respectively.

Table 4. Mean Correct RT (msec) and Mean IOR Effect (msec) as a function of Target Location and SOA in Experiment 10.

No. Cues	SOA	Target Location		IOR Effect	SOA	Target Location		IOR Effect	SOA	Target Location		IOR Effect
		1-back	uncued			2-back	uncued			3-back	uncued	
1	500	515	507	8								
	1000	478	452	26								
	1500	446	424	22								
	2000	422	408	14								
	2500	407	402	6								
	3000	417	401	16								
2	500	489	463	26	1000	475	463	12				
	1000	449	420	29	1500	434	420	14				
	1500	421	407	14	2000	410	407	3				
	2000	409	397	12	2500	405	397	8				
	2500	405	397	8	3000	397	396	1				
	3000	404	397	7	3500	406	397	8				
3	500	471	439	32	1000	456	439	17	1500	453	439	14
	1000	437	413	24	1500	427	413	14	2000	418	413	5
	1500	411	393	18	2000	416	393	23	2500	408	393	15
	2000	405	391	14	2500	403	391	12	3000	396	391	5
	2500	393	392	2	3000	393	392	2	3500	402	392	10
	3000	408	405	3	3500	405	405	0	4000	409	405	5

Cued one-back trials

A significant main effect of target location, F(1,49) = 129.34, MSe = 840.39, p < .001, indicated the presence of IOR. The main effects of number of cues, F(2,98) = 115.20, MSe = 984.22, p < .001, and SOA, F(5,245) = 177.00, MSe = 1649.35, p < .001, were both significant, reflecting a warning signal effect as observed in the previous experiments.

The interaction between target location and number of cues was not significant, F < 1, indicating that IOR did not vary as a function of number of cues. Importantly, the target location x SOA interaction was significant, F(5,245) = 8.86, MSe = 540.93, p < .001, reflecting the decay of the IOR effect with increasing SOA. That is, IOR effects were 22, 26, 18, 13, 5, and 9 msec at SOAs of 500, 1000, 1500, 2000, 2500, and 3000 msec, respectively. The number of cues x SOA interaction was also significant, F(10,490) = 14.75, MSe = 724.73, p < .001, reflecting that at short SOAs but not at long SOAs, RT decreased as the number of cues increased (i.e., the typical warning signal effect was observed).

The target location x number of cues x SOA interaction approached significance, F(10,490) = 1.77, MSe = 679.56, p < .07. Examination of the IOR effects as a function of number of cues and SOA reveals that IOR effects are smaller on a one-cue trial at an SOA of 500 msec relative to a two- and a three-cue trial but IOR effects are similar across subsequent SOAs for one-, two-, and three-cue trials.

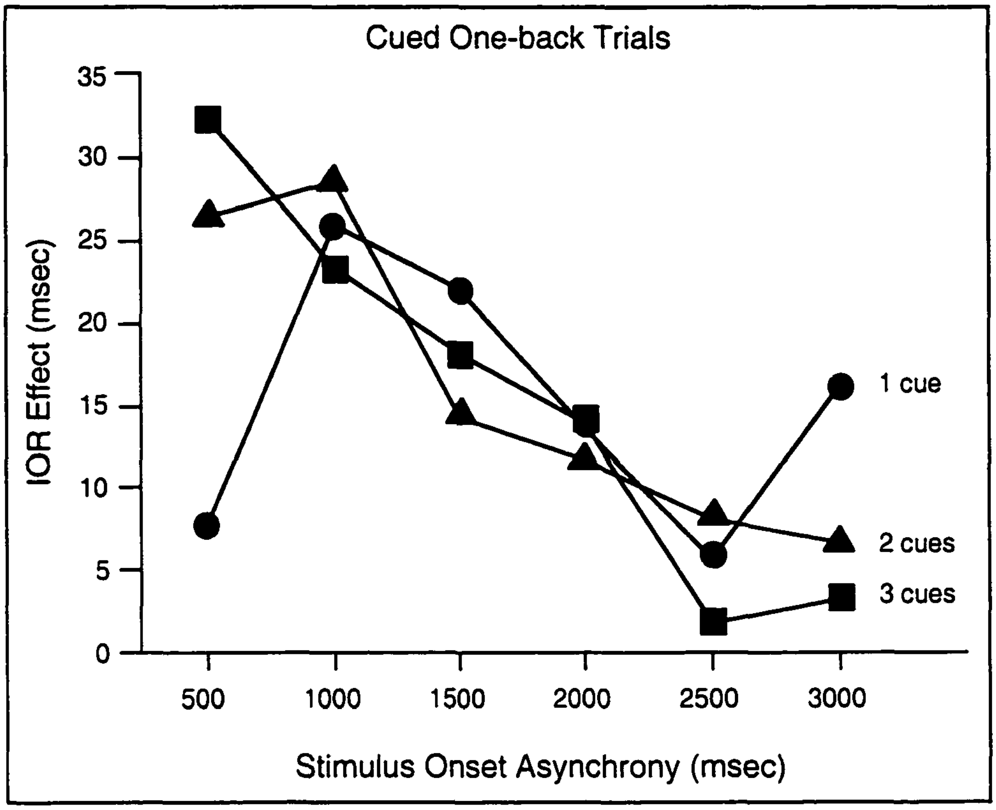

Figure 24. Mean IOR effects (msec) at a cued one-back location as a function of SOA and number of cues in Experiment 10.

Cued two-back trials

A significant main effect of target location, F(1,49) = 52.20, MSe = 512.89, p < .001, indicated the presence of IOR. The main effects of number of cues, F(1,49) = 13.75, MSe = 838.60, p < .001, and SOA, F(5,245) = 94.69, MSe = 1180.43, p < .001, were both significant as for the cued one-back trials.

The interaction between target location and number of cues was not significant, F(1,49) = 1.71, MSe = 557.86, p > .1. The target location x SOA interaction was again significant, F(5,245) = 2.61, MSe = 594.71, p < .05, reflecting the decay of the IOR effect with increasing SOA (15, 14, 13, 10, 1, and 4 msec at SOAs of 1000, 1500, 2000, 2500, 3000, and 3500 msec, respectively). The number of cues x SOA interaction was again significant, F(5,245) = 6.52, MSe = 524.70, p < .001, reflecting that at short SOAs but not at long SOAs, RT decreased as the number of cues increased.

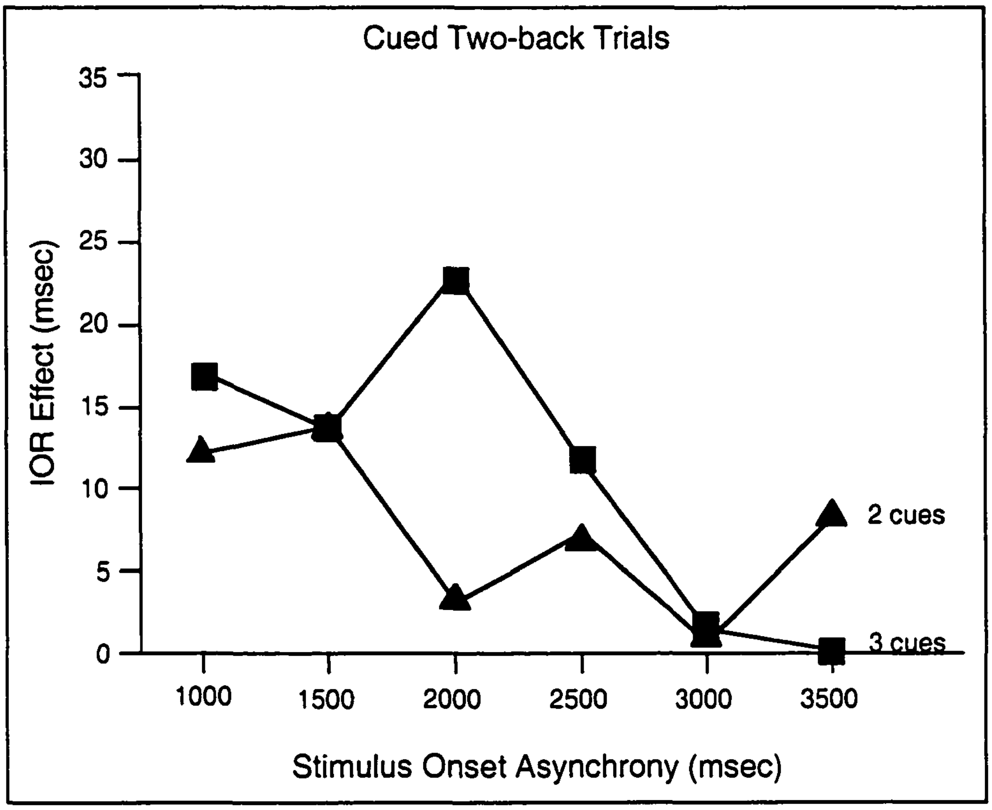

Figure 25. Mean IOR effect (msec) at a cued two-back location as a function of SOA and number of cues in Experiment 10.

The target location x number of cues x SOA interaction again approached significance, F(5,245) = 2.07, MSe = 517.18, p < .07. As was the case for the cued one-back trials, IOR effects are smaller on a two-cue trial at an SOA of 1000 msec relative to a three-cue trial but IOR effects are similar across subsequent SOAs for two-, and three-cue trials.

Cued three-back trials

The main effect of target location was significant, F(1,49) = 22.39, MSe = 528.82, p < .001, reflecting IOR. The main effect of SOA was significant, F(5,245) = 39.76, MSe = 935.93, p < .001, with a shorter RT at longer SOAs (446, 416, 400, 393, 397, and 407 msec for 1500, 2000, 2500, 3000, 3500, and 4000 msec, respectively). The target location x SOA interaction was not significant, F(5,245) = 1.14, MSe = 514.15, p > .3, reflecting that IOR did not vary systematically as a function of SOA.

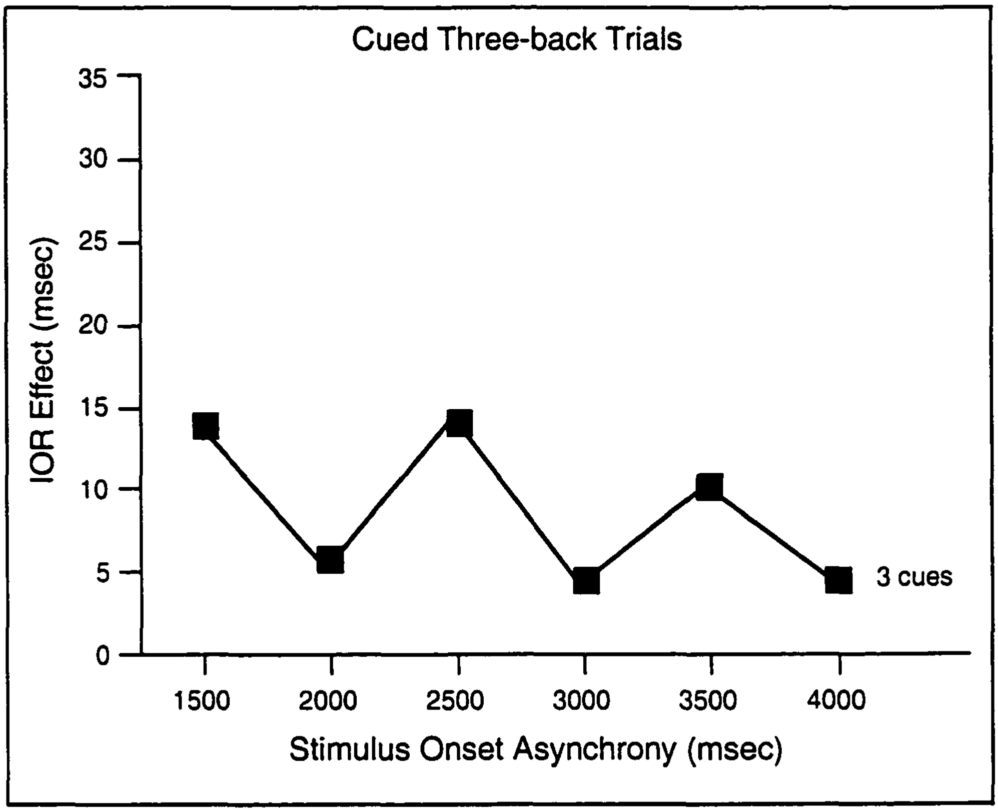

Figure 26. Mean IOR effect (msec) at a cued three-back location as a function of SOA and number of cues in Experiment 10.

Response accuracy

Overall mean error rates were again low (0.92%). False alarms accounted for the majority of the errors (0.58%) with misses and anticipations accounting for fewer errors (0.32% and 0.02% , respectively). Error analysis was conducted as in the previous experiments. The ANOVA revealed that the error rates varied significantly from each other, F(56,2744) = 7.96, MSe = .001, p < .001. Importantly, a post-hoc comparison showed that errors did not vary as a function of whether a target appeared at a cued versus an uncued location, F(1,2744) = 3.53, MSe = .001, p > .06.

Discussion

The cued one-back trials are of the greatest interest because they test concurrently for decay and the effect of the addition of cues. An examination of Figure 24 reveals that the IOR effect does, in fact, undergo temporal decay. At SOAs greater than 1000 msec, IOR systematically declines at a cued one-back location for one-, two-, and three-cue trials. Specifically, IOR effects for one-, two-, and three-cue trials are 26, 29, and 24 msec at 1000 msec SOA, 22, 14, and 18 msec at 1500 msec SOA, 14, 12, and 14 msec at 2000 msec SOA, and 6, 8, and 2 msec at 2500 msec SOA. Beyond an SOA of 2500 msec, the IOR effect appears to be somewhat less stable. At first glance, it appears that the conclusion drawn from Experiment 9, that the addition of cues underlies the monotonic function are invalid. But a closer look at Figure 24 shows that at a 500 msec cue-target SOA, the addition of cued locations does indeed affect the magnitude of the IOR effect (8, 26, and 32 msec for one-, two-, and three-cue trials, respectively). Thus, it is clear that the addition of cued locations plays a role in the monotonic decline of IOR across cued back locations when the SOA is less than 1000 msec. (From the observation in Experiment 9 that the IOR effect peaks at 750 msec, it is most likely the case that the addition of cued back locations plays a role at SOAs of 750 msec or less.)

It is also clear from Figure 24 that at SOAs of 1000 msec and greater, temporal decay is the primary component underlying the decline of IOR across cued back locations. This result supports the finding in Experiment 8 that the IOR effect declined more quickly in the 800 msec SOA condition.

The results from the cued two-back location must be interpreted with caution as the data does not appear to be stable. The instability of the data could have resulted from using a 500 msec cue-cue SOA. This study has established that IOR does not obtain its maximum effect for some 600 to 750 msec. The IOR effect may not have reached its peak before the onset of the final cue or may have simply been shorter than the optimal responding range adopted by participants. A more general observation though is that the pattern of IOR effects reflects, for the most part, the temporal decay of IOR. The IOR effect at a cued three-back location is too unstable to allow for any meaningful conclusions with respect to decay.

Thus, it appears that the decline in IOR results from two separate processes. At short SOAs, the addition of cued locations plays a critical role in the linear decline with a greater magnitude of IOR accruing to each additionally cued location. At long SOAs, decay of the inhibitory tags plays a critical role in the linear decline of IOR.

General Discussion

The following conclusions can be drawn from the present study. Experiments 7, 8, and 9 revealed that IOR effects can be measured reliably at five locations. Furthermore, in Experiments 7 and 8, the IOR magnitude was shown to decline in an approximately linear fashion from the most recently cued location to the least recently cued location.

Experiment 8 revealed two additional findings. First, although cue-target SOAs of 300 msec are sufficient for generating robust IOR effects in single cue IOR experiments, SOAs of 500 msec and greater are necessary to generate robust IOR and the characteristic monotonic function of multiple IOR. Second, the results suggest that the IOR effect may decay at an SOA of 800 msec. This possibility was tested further in Experiment 10.

Experiment 9 revealed that the introduction of additional cues appeared to be responsible for producing the monotonic function of multiple IOR. It appeared that a small amount of IOR developed at the first cued location and IOR increased with the addition of each cued location. Together the results from Experiments 8 and 9 suggest that the monotonic function of IOR reflects the addition of cued locations rather than a temporal decay of the inhibitory tags. However, in the 800 msec SOA condition of Experiment 8, IOR appeared to be declining at a faster rate than for the shorter SOA conditions. Thus, it could be the case that the observation of a decay process requires an SOA of greater than 800 msec.

In Experiment 10, the factors of additional cued locations and temporal decay were combined to clarify the role that each factor plays. Results showed that the addition of cues plays a role at SOAs less than 1000 msec whereas temporal decay of the inhibitory tags plays a role at longer SOAs.

In all of the experiments conducted thus far, an attentional orienting paradigm has been used to direct attention to locations in the search display and then onset a single target was onset at either a previously cued or an uncued location. One issue that arises is whether IOR is useful in a search task where the target appears amongst distractors (i.e.. nontargets items). This question is addressed in Chapter 6 by coupling a covert orienting paradigm with a traditional visual search paradigm.

CHAPTER 6: INHIBITION OF RETURN IN VISUAL SEARCH TASKS

The goal of this chapter was to determine whether IOR effects obtained in a covert orienting paradigm can transfer to a traditional visual search paradigm where a target item must be discriminated from distractor items. A sequential cuing paradigm was used to direct attention to locations prior to the appearance of a visual search display containing one target, that required a discrimination response among distractors.

In Experiment 11, when a serial search display (i.e., distractors were heterogeneous) was presented following the cuing sequence, IOR was found at each of the cued back locations with the most recently cued location showing the largest IOR effect (i.e., longest RT). These results demonstrate that IOR obtained in an orienting paradigm affects the manner in which observers search for a feature conjunction target. Furthermore, the notion that IOR is a mechanism that promotes efficient visual search was supported by the fact that RT was longest at the most recently attended location. That is, it appears that the most recently cued/attended location was searched last.

In Experiment 12, when a parallel search display (i.e., distractors were homogenous) was presented following the cuing sequence, IOR effects were again obtained at all of the cued locations. Interestingly, the IOR effects were consistently smaller than for the serial search task. This finding suggests that IOR could be of greater benefit in more difficult search situations.

Experiment 13 was conducted as a control experiment to ensure that the search displays designated serial and parallel did in fact induce serial and parallel search.

Experiment 11

Although it is generally agreed that IOR serves as a facilitator of efficient visual search, there is a missing link in the literature connecting IOR to visual search. As discussed in Chapter 2, two approaches have been taken to investigate the connection between IOR and visual search. One approach involves conducting a visual search to determine whether a target item is present or absent in a search display followed by the presentation of a probe item requiring a detection response (Klein, 1988; Klein & MacInnes, 1999; Müller & von Mühlenen, in press). IOR is inferred, if RT is longer when a probe item is at a location that was likely to have been searched than when a probe item is at location that was not likely to have been searched (i.e., an empty location). These studies are based on the premise that, as participants search locations, IOR is established at the inspected locations.

A second approach used by many investigators, and in this thesis, involves using modifications of the attentional orienting paradigm. Here, attention is directed to specific locations and then the presence of IOR is determined if RT is longer at a cued location than at an uncued location.

Each of these approaches, however, is somewhat incomplete. The visual search paradigm has the advantage in that the search is natural, with participants conducting searches volitionally, but it suffers in that there is no way of determining where covert attention went or when it went there. Therefore, if IOR is observed at one location but not at the other location, the assumption made is that attention was allocated to that location. Given that there appears to be a finite number of locations that can be inhibited in a search (see Chapter 5), failure to trace attention in such a paradigm where the number of distractor items could be larger than the number of available inhibitory "tags" could have far-reaching consequences. For instance, it could be the case, that IOR cannot be inferred not because the location was not attended but rather that it was attended early on in the search.

Conversely, the attentional orienting paradigm has the advantage that where covert attention went and when it went there can be traced since attention is systematically directed to particular locations. On the other hand, "forced" orienting hardly constitutes the type of search that is normally conducted in the environment. It remains unclear whether IOR found using this paradigm generalizes to everyday search situations.

The aim in this experiment was to determine whether IOR obtained with an attentional orienting paradigm transfers to a traditional visual search paradigm. An attentional orienting paradigm was used to direct attention sequentially to locations in the display and thereby establish IOR at cued locations. Then, a serial search requiring target discrimination was presented to determine whether IOR transfers onto a visual search situation involving the discrimination of a target item surrounded by dissimilar distractor items. If IOR is successfully transferred to the search display, then based on the results from Chapter 5, the expectation is that the most recently cued location will have the greatest magnitude of IOR (i.e., have the longest RT) with the IOR effect declining systematically across less recently cued locations.

Method

Participants

Forty undergraduates participated for course credit. Seven participants were replaced because of high error rates (greater than 20% wrong key presses). All reported normal or corrected-to-normal vision.

Stimuli and Procedure

The stimulus display consisted of a black background with eight dark-gray rectangular figure-eights surrounding a 0.5° x 0.5° of visual angle light-gray central fixation cross. The figure-eights measured 1.5° in height and 1.0° in width. These stimuli served as placeholders and were placed equidistantly around an imaginary circle having a radius of 6.5° from the center of the circle to the middle of each placeholder. The first placeholder was centered on the vertical meridian and the last placeholder was located at an angle of 45° to the left of the vertical meridian.

Cuing was accomplished by superimposing a light-gray placeholder over a dark-gray placeholder. All cue durations were 200 msec. The removal of from one to three of the seven segments forming each figure-eight revealed a target and seven distractors letters. The target letter was equally often a "P" or an "E". When the target was a "P", the lower right vertical segment and the bottom horizontal segment were removed. When the target was an "E", the two right vertical segments were removed. The distractor letters were "A", "C", "F", "H", "O", "S", and "U". The letters "A" and "O" required the removal of a single segment, "H", "U", and "S" required the removal of two segments, and the "C" and "F" required the removal of three segments (see Figure 27, Panel A). Participants were instructed to press the "z" key if an "E" appeared in the search display or to press the "/" key if a "P" appeared.

Four cues always appeared prior to target onset with the SOA between all stimuli (cues and target) fixed at 600 msec. Each trial began with a 100 msec warning tone. Six hundred milliseconds following the onset of the warning tone, a placeholder was cued, followed by the sequential cuing of three different placeholders. The search display was generated as described above with the removal of line segments from the figure-eights to reveal eight different letters (one target and seven distractors). Following a keypress or after 3000 msec had elapsed, whichever came first, the placeholders were restored to figure-eights. Catch trials (i.e., no target appeared) occurred after four cues. The intertrial interval was 1000 ms. An experimental session lasted approximately 50 minutes.

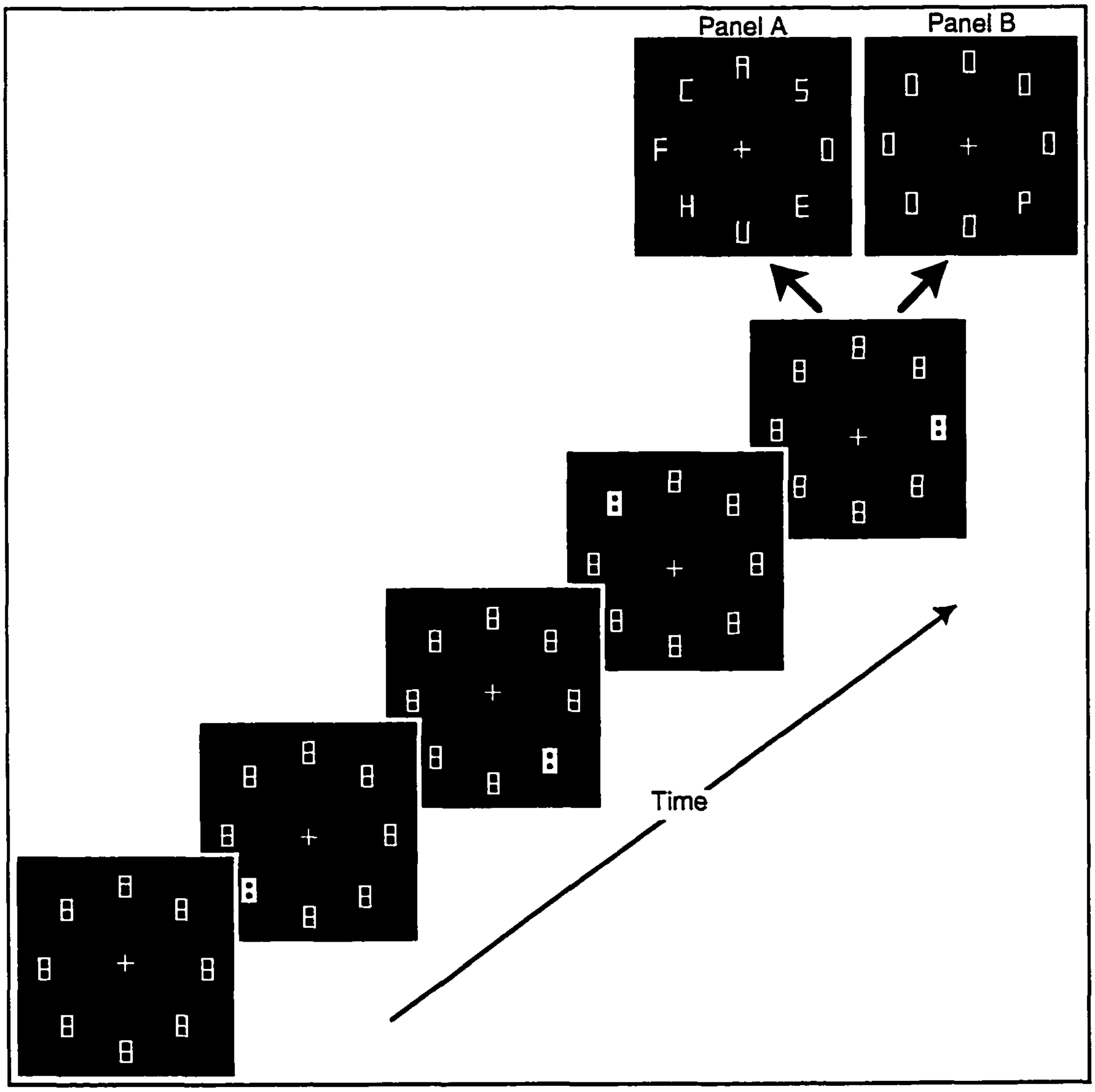

Figure 27. The sequence of events on a trial in Experiment 11 (Panel A, the target is an "E") and Experiment 12 (Panel B, the target is a "P"). Four of the placeholders are cued sequentially prior to the appearance of the visual search array. In the example above, the target "P" or "E" appears at a cued three-back location.

Design

In a single session, participants received 24 practice trials followed by eight blocks of 48 test trials, for a total of 384 test trials. The 384 test trials consisted of equal numbers of cued and uncued trials. Of the 162 cued trials, there were 48 trials where the target appeared at each of four cued placeholders (i.e., cued one-, two-, three-, and four-back locations). On the remaining trials, the target appeared in the four remaining uncued placeholders. On half of the trials, the target was the letter "P" and on the other half of the trials, the target was the letter "E".

Results

A one-factor ANOVA was conducted with target location as the factor. Mean correct RT as a function of target location is presented in Figure 28.

A significant main effect for target location was observed, *F*(4, 156) = 8.17, *MSe* = 3403.89, *p* < .001, with longer RT at a one-, two-, three-, and four-back location (1148, 1118, 1105, and 1092 msec, respectively) than at an uncued location (1079 msec). A planned contrast of the cued-back versus the uncued locations, confirmed the presence of IOR, *F*(1, 156) = 12.95, *MSe* = 3403.89, *p* < .001.

As was observed in the previous experiments, the magnitude of the IOR effect declined across cued back locations with IOR (69, 39, 26, and 14 msec at a one-back, two-back, three-back, and four-back location , respectively).

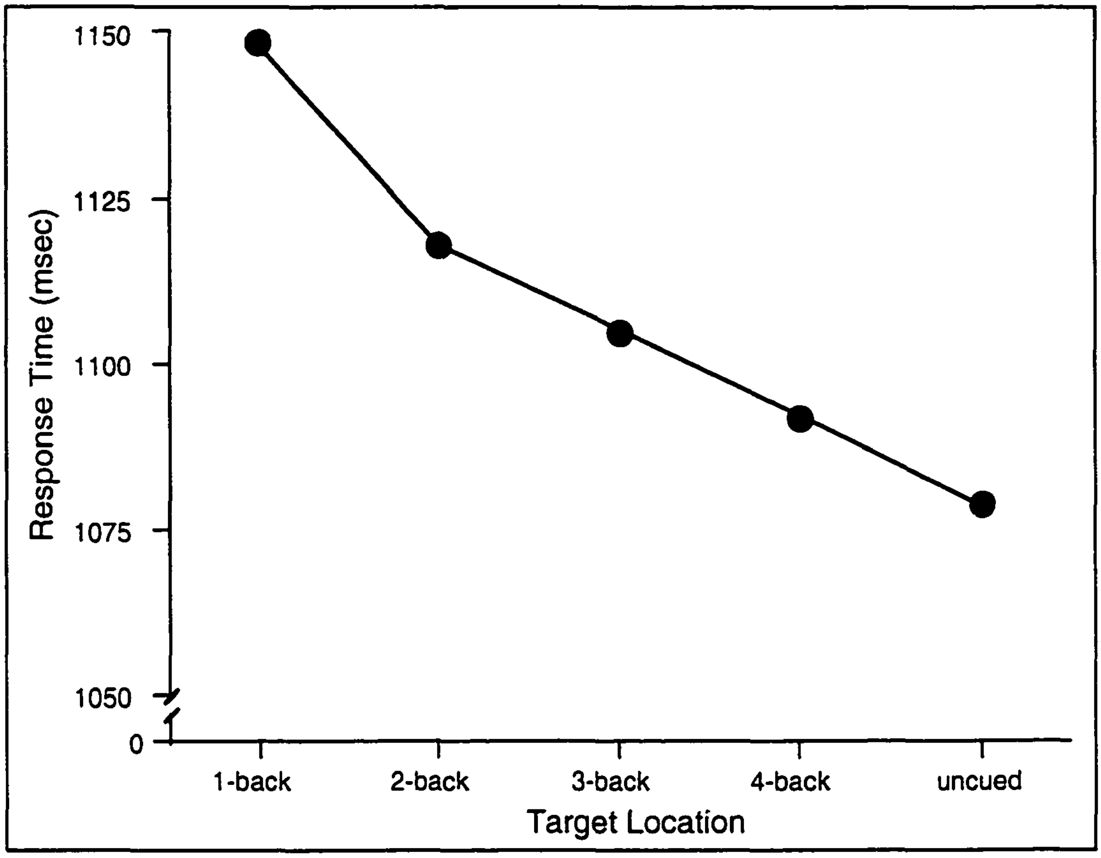

Figure 28. Mean correct RT (msec) as a function of target location in Experiment 11.

Response Accuracy

The mean error rate was 7.9% with errors being wrong key presses (7.2%), misses (0.7%), and false alarms (<0.1%). Error data were analysed as in previous experiments. The ANOVA revealed that there were no differences in error rates, $F(4, 156) = 1.08$, $MSe = .001$, $p > .3$. Thus, the IOR effects observed here do not reflect a tradeoff between response speed and response accuracy.

Discussion

The results from this experiment are straightforward. IOR effects obtained with an attentional orienting paradigm transfer to a visual search paradigm. Additionally, the systematic decline in the magnitude of IOR from the most recently cued location to the least recently cued location offers assurance that combining the attentional orienting and visual search paradigms does not alter the IOR effect of the orienting paradigm. Thus, the present experiment supports the idea that IOR improves the efficiency of serial search with a target occurring in uncued (unsearched) locations being identified sooner than a target in a cued location. Furthermore, when a target was not located in an uncued location, cued locations appear to have been searched systematically with the most recently cued (attended) location being searched last. This is precisely the result that one would expect if IOR serves to facilitate efficient search by biasing attention against returning to previously inspected locations.

A further question concerns whether differential effects can be found when search is conducted in a spatially parallel manner. In Experiment 12, this issue was addressed.

Experiment 12

In normal search situations, IOR effects are not expected for parallel search because parallel search is believed to be accomplished without the direction of attention to discrete individual items in the display (see Treisman, 1988; but see also Wolfe, 1998b for another view). In Experiment 11, however, it was demonstrated that IOR can be established in a sequential search paradigm prior to the presentation of a search display and that the IOR effects "hold" from the cue display to the search display. Therefore, the expectation is that IOR would be obtained by the attentional orienting paradigm and evidence of IOR would be obtained in parallel search. The question here is whether there would be a difference in IOR effects for serial versus parallel search.

Method

Participants

Forty undergraduates participated for course credit. One participant was replaced because of high error rates (<20%). All reported normal or corrected-to-normal vision.

Stimuli and Procedure

Stimuli and procedure were the same as those used in Experiment 11 with the following exceptions. All distractors were the letter "O". The search display remained on the screen for a maximum of 2000 msec.

Results

Data analyses were conducted as in Experiment 11. Mean correct RT as a function of target location is presented in Figure 29. A significant main effect for target location was observed, $\underline{F}(4, 156) = 11.77$, $\underline{MSe} = 1089.13$, $\underline{p} < .001$, with longer RT at a one-, two-, three-, and four-back location (821, 802, 785, and 783 msec, respectively) than at an uncued location (778 msec). A planned contrast of the cued-back versus the uncued locations, confirmed the presence of IOR, $\underline{F}(1, 156) = 12.11$, $\underline{MSe} = 1089.13$, $\underline{p} < .001$.

As observed in the previous experiment, magnitude of the IOR effect declined across cued-back locations (43, 24, 8, and 5 msec at a one-, two-, three, and four-back location, respectively).

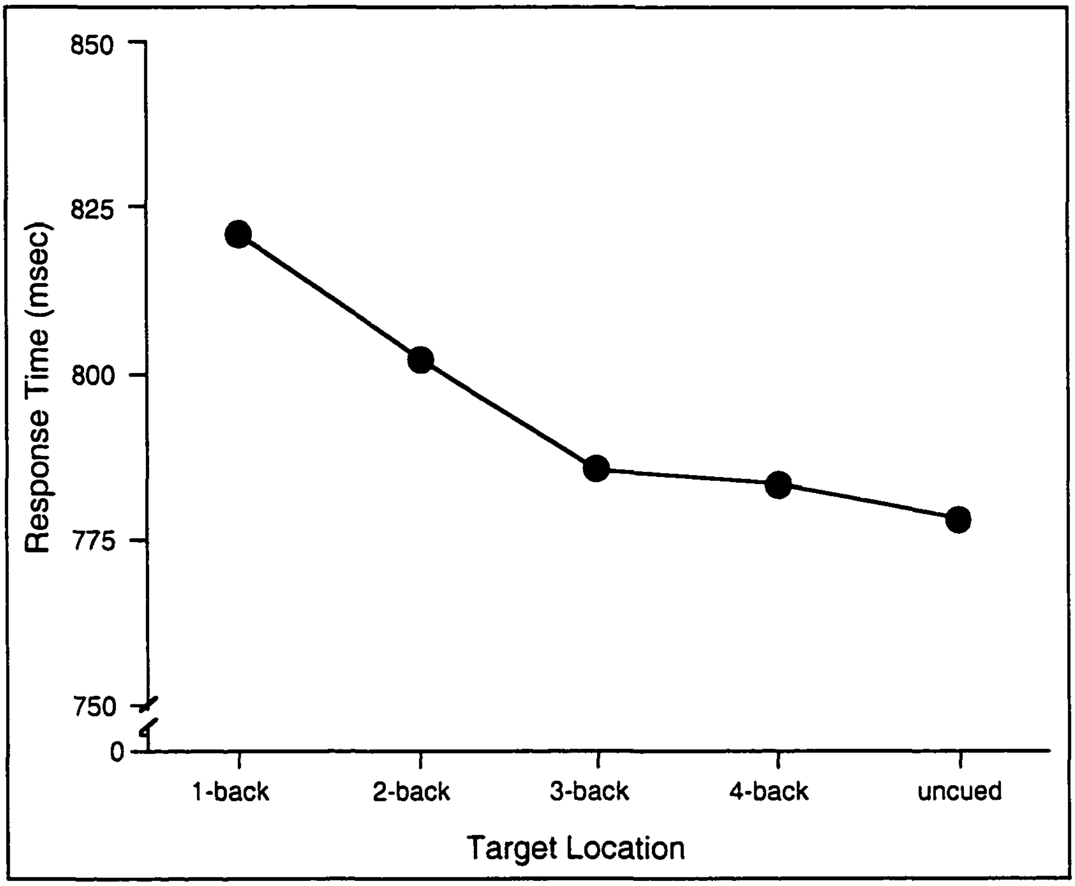

Figure 29. Mean correct RT (msec) as a function of target location in Experiment 12.

Response Accuracy

The mean error rate was 7.36% with errors being wrong key presses (6.51%), misses (0.64%), and false alarms (0.21%). Error data were analysed as in previous experiments. The ANOVA revealed that there were no differences in error rates, $\underline{F}(4, 156) = 1.43$, $\underline{MSe} = .001$, $\underline{p} > .2$. Thus, the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

The goal was to determine whether differences in the IOR effect would be found between serial and parallel search. The results from the present experiment indicated that he IOR effects for cued one- through four-back locations for parallel search (44, 24, 8, and

5 msec respectively) differed significantly from the IOR effects for serial search (69, 39, 26, and 14 msec respectively), $t(3) = 4.83$, $p < .05$.

Why might this differential effect between serial and parallel search arise? The most reasonable explanation is that because IOR is largely an attentional phenomenon, its effects should be more pronounced when search is more attentionally-demanding (i.e., in serial rather than in parallel search). However, prior to accepting the conclusion that IOR operates differentially in serial and parallel search, it is necessary to demonstrate that the search tasks used in Experiments 11 and 12 were, in fact, serial and parallel searches, respectively. In Experiment 13, observers received only the serial and parallel search tasks. It is important to point out that the larger IOR effects observed in the serial search task are not simply proportional to the longer RT in the serial search task. IOR effects were 32.5% higher, on average, for serial than for parallel search. This finding supports the idea that IOR is of greater benefit in attentionally-demanding searches.

Experiment 13

In the present experiment, the search task was presented alone to determine that the search tasks described in Experiments 11 and 12 involved serial and parallel search, respectively. Although the practice of adopting a strict dichotomy to distinguish between parallel and serial search has been challenged (Wolfe, 1998a, 1998b), a search rate of 10 msec or less per item is considered to reflect parallel or efficient search and a search rate greater than 20 msec or more per item is considered to reflect serial or inefficient search.

Method

Participants

Thirteen undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Stimuli and Procedure

The stimulus display was identical to the final frames shown in Experiments 11 and 12 (see Figure 27, Panels A and B) with the following exceptions. Set size was varied with four, six, or eight letters surrounding the central fixation cross. For the serial search task, the distractor letters were randomly chosen from amongst the same letters used in Experiment 11 ("A", "C", "F", "H", "O", "S", and "U"). For the parallel search task, as in Experiment 12, the distractor letters were all "O"s. As in the previous experiments, the target letter was equally often either a "P" or an "E".

A central fixation cross was displayed on the computer screen at the start of a block of trials and remained for the duration of the block. Each trial began with a 100 msec warning tone. Six hundred msec following the onset of the warning tone, a search display of four, six, or eight letters appeared. The search display was offset following a keypress or termination of the trial due to a missed response. As in the previous experiments, a response was considered missed when 3000 msec had elapsed after search display onset in serial search trials or when 2000 msec had elapsed after search display onset in parallel search trials.

Design

Search tasks (serial and parallel) were blocked and the order of the conditions was counterbalanced across participants. In each of the search conditions, participants received 20 practice trials followed by 10 blocks of 48 test trials. The 480 test trials in each search task consisted of equal numbers of set size four, six, and eight trials and were chosen randomly.

Results

Mean correct RT as a function of display size is presented in Figure 30. A two-factor ANOVA was conducted with search task (serial, parallel) and set size (4, 6, 8) as factors. A significant main effect of search task was observed, *F*(1,12) = 71.65, *MSe* = 8982.84, *p* < .001, reflecting longer RT for the serial search task (696 msec) than for the parallel search task (514 msec). There was also a significant main effect of set size, *F*(2, 12) = 55.64, *MSe* = 992.55, *p* < .001, indicating that RT increased as set size increased (560, 603, and 652 msec for set sizes of 4, 6, and 8, respectively). Importantly, an interaction between search task and set size was observed, *F*(2, 24) = 32.69, *MSe* = 952.05, *p* < .001. A linear regression analysis of RT versus set size was conducted to examine the slope functions. In the serial search task, set size accounted for 99.9% of the RT variance, *F*(1, 1) = 1492.36, *MSe* = 8.72, p < .02. The slope of this linear regression indicated that search occurred at a rate of 40.3 msec/item (see Figure 30). In the parallel search task, set size did not account for the RT variance, *F*(1, 1) = 69.93, *MSe* = 4.17, p > .05. The slope of the linear regression indicated that search occurred at a rate of 5.7 msec/item.

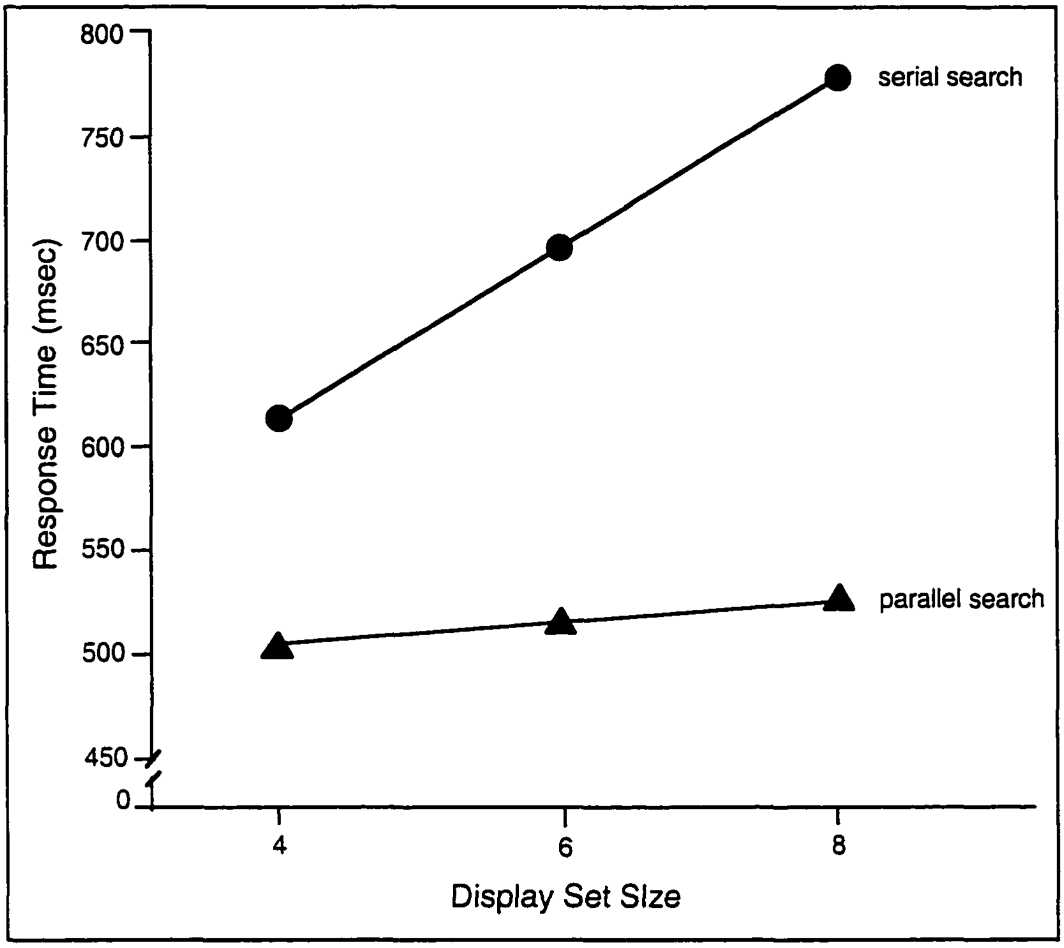

Figure 30. Results from Experiment 13 with mean correct RT (msec) for serial and parallel search as a function of display set size.

Response Accuracy

The mean error rate for the serial search was 7.39% with errors being wrong key presses (7.21%), missed responses (0.17%), and anticipatory responses (0.02%). Error data were analysed with separate repeated measures ANOVA for serial and parallel search with set size as a factor. The ANOVA revealed an effect for set size, F(2, 24) = 20.07, MSe = 0.0003, $p < .001$, (.06, .07, and .10% errors for set sizes of 4, 6, and 8, respectively), reflecting an increase in errors as a function of set size. The mean error rate for the parallel search trials was 4.46% with errors being wrong key presses (4.40%), missed responses (0.05%), and anticipatory responses (0.01%). The ANOVA revealed no significant main effect of set size, $F(2, 24) = 2.80$, $MSe = 0.0003$, $p > .05$, reflecting no differences in errors as a function of set size. Error rates were higher in the serial search relative to the parallel search. Thus, the differences in the RT pattern observed between the serial and parallel search do not reflect a tradeoff between response speed and response accuracy.

Discussion

This control experiment was conducted to ensure that search tasks used in Experiments 11 and 12 were serial and parallel search tasks, respectively. The results from the regression analyses confirm that the search conditions designated as serial and parallel were, in fact, such searches. Furthermore, the error patterns also reflect serial and parallel searches with more errors occurring as set size increases for serial but not for parallel search.

General Discussion

Previous research has suggested that IOR plays an important role in visual search by inhibiting the re-inspection of locations that have already been examined. However, to date, the evidence has been indirect due to paradigmatic limitations. Therefore, it was important to determine whether the IOR effect established with an attentional orienting paradigm transfers to a visual search paradigm. Experiment 11 demonstrated that (a) IOR can be obtained at cued locations using an attentional orienting paradigm and (b) the effects of IOR so obtained influence serial search in a manner that is consistent with a mechanism facilitating visual search. That is, RT was shorter for an uncued location than for a cued location, with RT longest for the more recently cued locations. This finding supports the view that search was biased against locations that had been recently attended.

Experiment 12 revealed that IOR is of a greater benefit in serial than in parallel search since the magnitude of the IOR effect at each cued back location was greater for serial than for parallel search. This finding is important because greater attentional requirements should reflect greater dependence on IOR. It is important to note that IOR cannot influence the order of search in parallel search. It can, however, affect the availability of the search items. Hence, IOR can have an effect in parallel search. These results are consistent with the notion that IOR is a facilitator of efficient visual search.

Experiment 13 demonstrated that the search tasks performed in Experiments 11 and 12 were serial and parallel search respectively.

Does this finding provide conclusive evidence of the role of IOR in visual searches that are conducted in daily life? No, it does not. There is an important difference between the attentional orienting paradigm used to generate multiple IOR and the search that occurs in daily life that requires consideration. The attentional orienting paradigm is somewhat artificial in that attention was moved exogenously via peripheral cues whereas in daily life, attention and eye movements are moved endogenously to an object or item of interest. However, in the paradigm used in this study, although attention was reflexively drawn to the abrupt luminance change following that manipulation, participants were free to covertly examine the search display at will as is the case in the everyday search. From the results, it is clear that uncued locations were searched prior to the "re-examination" of the cued locations. Furthermore, the paradigm used in the present study has provided the first demonstration that IOR can be found when more than one distractor accompanies the target. This finding is significant because it is more typical of the complex searches accomplished in daily life. Therefore, although these findings alone do not provide conclusive evidence that IOR plays a role in search, when taken together with previous IOR results, they lend further support to the hypothesis that IOR plays a role in search.

It is important to note that multiple IOR was not obtained in a previous attempt to couple an attentional orienting paradigm with a visual search paradigm. In that unreported pilot study, from one to three of the five outline placeholders were cued prior to the appearance of a search display. A key difference between that experiment and the present one was that a target or a distractor was abruptly onset into the center of each placeholder rather than having segments of the placeholder offset to reveal a target or a distractor. This failure to obtain IOR motivated the design of the paradigm for the present experiments. But why was IOR not obtained in the previous study when the search display was abruptly onset after IOR was presumably established? One possibility is that onsetting a search array that is equivalent in the number of elements already present on the screen, "resets" all attentional effects, including any inhibitory tags that were placed at the cued locations. It is not difficult to imagine that resetting the attentional system could have considerable benefits if a substantial portion of the visual field suddenly changed.

How then does the present study fit with Horowitz and Wolfe's (1998) finding that visual search is amnestic? As suggested by these authors, although common sense dictates that searched and rejected items should be somehow noted to avoid costly re-inspection, common sense appears to be wrong. In that study, participants reported whether a target letter "T" was present or absent among distractor letter "L"s. In one condition, the search items remained in the same locations throughout the trial and in the other condition, the stimulus locations were changed every 111 msec. If search has a memory, one would expect that search should be more efficient in the first condition relative to the second condition where search memory would be continually disrupted as the stimuli changed locations. The results revealed that search function was the same in both conditions, allowing for the conclusion that search is memoryless. However, the present work indicates that searched locations are tagged with inhibition and re-inspection of these locations is discouraged. The critical factor here may be that whereas Horowitz and Wolfe's study involved the offset and re-onset of search elements, the present study did not. It is probable that the inhibitory tags remained with the cued figure-eights in the present study because only a small portion (i.e., a maximum of three of seven elements) of the placeholder was removed to reveal the search display. Thus, the IOR that accrued to either the location or the object should not have been disturbed. In the Horowitz and Wolfe study, the search elements were repeatedly offset and re-onset. Together with the Müller and von Mühlenen (in press) and Takeda and Yagi (in press) studies, indicating that removal of the search display has a severe and negative impact on the development of IOR, the present data suggest that search does have a memory and that the memory is IOR.

The present work may also provide some insight on the phenomenon described as visual marking, a mechanism proposed by Watson and Humphreys (1997, 1998) for prioritizing the selection of new items. Based on evidence from three experiments, Watson and Humphrey's (1997) concluded that IOR and visual marking are different phenomena although they share some properties (e.g., both are generated in the absence of eye movements to the cued or precued locations and have the same time course). In the visual marking paradigm, a set of distractors (e.g., green "H"s) appeared 1000 msec prior to the onset of a different set of distractors (e.g., blue "A"s) that contained a target letter (e.g., a blue "H") on half of the trials. Visual marking represents the finding that RT indicating the presence or absence of a target letter in this situation was shorter relative to the situation where both sets of distractors were presented at the same time. IOR was considered as one of five candidate mechanisms mediating visual marking but was ruled out in three tests of that hypothesis.

The three tests of that hypothesis differed from the visual marking paradigm described above in that the form of the initial set of distractors was altered. In the first test, the distractors were green partial "H"s containing only two of the five elements making up the letter "H". In the second test, the initial set of green distractors were 10 element figures -- figure-eight plus a vertical line in the upper half and a cross in the lower half. In the third test, the initial set of green distractors were solid blocks of green. These distractors were onset prior to the addition (test 1) or removal (tests 2 and 3) of segments to yield green distractor "H"s plus the onset of the blue second distractor set and, on half of the trials, the blue target. The hypothesis was that if IOR was the mechanism underlying visual marking, then the locations occupied by the initial distractors should be inhibited and the search time should have been shorter than for the condition where all distractors were onset simultaneously. No difference in search time between the two search conditions was observed, allowing for the conclusion that visual marking was not characterized by inhibition of previously cued locations. Note that in all cases, the initial distractors became five segment "H"s. All of the tests were based on the premise that adding to or subtracting from the number of segments comprising the initial distractors would not interfere with inhibition if it were generated with the precuing of the green "H" distractors. However, as demonstrated by previous studies (Müller and von Mühlenen, in press; Takeda & Yagi, in press) and the reported pilot study that failed to obtain multiple IOR in a visual search task where the search display was onset after cuing the placeholders, it is clear that such manipulations do, in fact, eliminate IOR effects. It is unknown whether IOR is simply not generated in such paradigms or the inhibitory tags are removed when the visual field is disturbed by substantial amounts of onset or offset activity but it is known that such transients result in a loss of IOR.

Another possibility is that multiple IOR is object-based rather than location-based. If this is the case, then in order to observe IOR, the elements in the search display would have to be cued (as occurred in the present study). According to this view, the failure to observe IOR in the reported pilot experiment resulted because the elements in the search display were not cued. This explanation is consistent with recent studies demonstrating that the observation of IOR effects is dependent on the search display remaining present (Müller & von Mühlenen, in press; Takeda & Yagi, in press).

In Chapter 7, the possibility is explored that the multiple IOR generated in the experiments discussed in this thesis are composed of location- and an object-based effects.

CHAPTER 7: MULTIPLE LOCATION INHIBITION OF RETURN: LOCATION-BASED AND/OR OBJECT-BASED?

Tipper et al. (1991) suggested that the type of IOR generated when searching for a stationary object in a static environment would not be beneficial when searching for a moving object among other moving objects. They argued that, in this case, not returning attention to previously searched objects would require an object-based IOR. Tipper and colleagues (Tipper et al., 1991, Tipper et al., 1994, Tipper & Weaver, 1998) have demonstrated that when a placeholder is cued and then moved, IOR is found both at the old location of the cued placeholder (i.e., location-based IOR) and at the new location of the cued placeholder (i.e., object-based IOR). More recently, Jordan and Tipper (1998) reported that the IOR generated in static displays is composed of both location-based and object-based IOR[5]. The aim of the present chapter is to determine whether multiple IOR is location-based, object-based, or both.

In Experiment 14, two different multiple IOR paradigms were used to parse total IOR effects into location-based IOR effects and object-based IOR effects. Location-based plus object-based IOR was measured with the multiple IOR paradigm used throughout this thesis. Specifically, outline placeholders were visible throughout the trial. Location-based IOR was measured with the same multiple IOR paradigm with the exception that placeholders were not visible. This manipulation was intended to generate a pure measure of location-based IOR by preventing IOR from accruing to the object representation of the placeholder. If multiple IOR is comprised of both location- and object-based effects or purely object-based IOR, then larger IOR effects are expected when placeholders are present than when placeholders are absent because both location-based and/or object-

---

[5] It must be noted that the object-based IOR referred to in this study is restricted to static displays. Abrams, Christ, and Smith (1999) have recently demonstrated that the object-based IOR found in static and dynamic displays may be fundamentally different.

based effects should accrue to the placeholders. Object-based effects were determined by subtracting location-based effects in the placeholders-absent paradigm from the total (location-based plus object-based) IOR effects in the placeholders-present paradigm. Surprisingly, there were no difference in the magnitude of the IOR effects between the two paradigms suggesting that multiple IOR is exclusively a location-based phenomenon.

An alternate explanation of why a differential effect was not found between the two paradigms was that in the placeholders-present paradigm, IOR accrued to the perimeter of the placeholder (i.e., the part of the object that was cued) rather than to the entire object. Since the target is located at the center of the placeholder, it was possible that an object-based IOR would not be operating at that spatial position. Experiment 15 was a replication of Experiment 14 with solid placeholders present to facilitate the formation of object-based IOR across the cued object. Again, no differences were found in the magnitude of the IOR effects between the placeholders-present and placeholders-absent paradigms, thus arguing for the conclusion that multiple IOR is a location-based but not an object-based phenomenon.

Experiment 14

In Experiment 14, the issue examined was whether the IOR generated in the multiple IOR paradigm has an object-based as well as a location-based component. Observers were presented with two paradigms. In the first paradigm, placeholders were present for the duration of the trial as was the case in the multiple IOR experiments conducted thus far. This manipulation was intended to generate both location-based and object-based IOR. In the second paradigm, the paradigm was the same except that placeholders were absent from the display. This manipulation was intended to generate location-based IOR only.

Method

Participants

Twenty-five undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Stimuli and Procedure

Stimuli were identical to Experiment 7 with the exception that six, rather than eight, dark-gray outline placeholders were present in the display. The first placeholder was centered on the vertical meridian and the last placeholder was located at an angle of 60° to the left of the vertical meridian.

Cue durations were 200 msec. The target remained present until a response was recorded or 1500 msec had elapsed, whichever occurred first. The intertrial interval was 1000 msec. The SOA between all stimuli (cues and target) was fixed at 700 msec.

Each trial began with a 100 msec warning tone. Following a 500 msec SOA, one of the placeholders was cued. Following a 700 msec SOA, either a target (an asterisk) appeared or a second placeholder could be cued. Up to four peripheral cues could precede target onset. On catch (no target) trials four cues appeared.

Design

In a single 30 minute session, observers were presented with two different paradigms (placeholders-present measuring location-based plus object-based IOR, placeholders-absent measuring location-based IOR). For each paradigm, there were 216 trials divided into 4 blocks of 54 trials. Of these 216 trials, 24 were catch trials. The remaining 192 trials were divided equally among the four cue conditions (i.e., one-, two-, three-, four-cue trials) resulting in 48 trials per cue. On one-cue trials, the target would appear eight times at the cued location and eight times at each of the five uncued locations. Similarly, for the four-cue trials, the target would appear eight times at each of the four cued locations and eight times at each of the two uncued locations. For each of the two paradigms, participants first received 10 practice trials. The order of paradigm presentation was counterbalanced across participants.

Results

Separate repeated measures ANOVAs were performed for each of the cued-back locations (one-back through to four-back). For one-back through three-back location trials, a three-factor ANOVA was conducted with paradigm (placeholders-present, placeholders absent), target location (cued n-back vs. uncued) and number of cues as factors. For the four-back location trials, a two-factor ANOVA was conducted with paradigm (placeholders-present, placeholders absent), and target location (cued four-back vs. uncued) as factors. Mean correct RT as a function of paradigm and target location is presented in Table 5 and Figure 31.

Table 5. Mean Correct RT (msec) and Mean IOR Effect (msec) for the Placeholder-present and Placeholder-absent Paradigms as a function of Target Location and Number of Cues in Experiment 14.

Target Location	Placeholders-present								Placeholders-absent							
	Number of cues								Number of Cues							
	1		2		3		4		1		2		3		4	
	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR
uncued	468		423		391		387		471		432		403		383	
1-back	480	12	444	21	427	37	412	24	481	11	457	26	417	13	422	38
2-back			424	1	409	18	419	32			451	20	407	4	413	30
3-back					413	22	404	16					406	2	406	23
4-back							406	19							396	13

Cued one-back trials

The main effect of paradigm was not significant, F < 1, indicating that RT did not differ as a function of whether the placeholders were present or absent in the display. A significant main effect was found for target location, F(1, 24) = 31.18, MSe = 1662.22, p < .001, indicating a 23 msec IOR effect. The main effect number of cues was also significant. F(3. 72) = 76.31. MSe = 1464.91. p < .001. revealing a warning signal effect.

Surprisingly, a significant interaction was not observed for paradigm x target location. F < 1. indicating that total IOR effects did not differ from location-based IOR effects. None of the other interactions was significant (paradigm x number of cues, F < 1. target location x number of cues, F(3, 72) = 2.51, MSe = 686.27, p > .06, paradigm x target location x number of cues, F(3, 72) = 2.03, MSe = 768.43, p > .12).

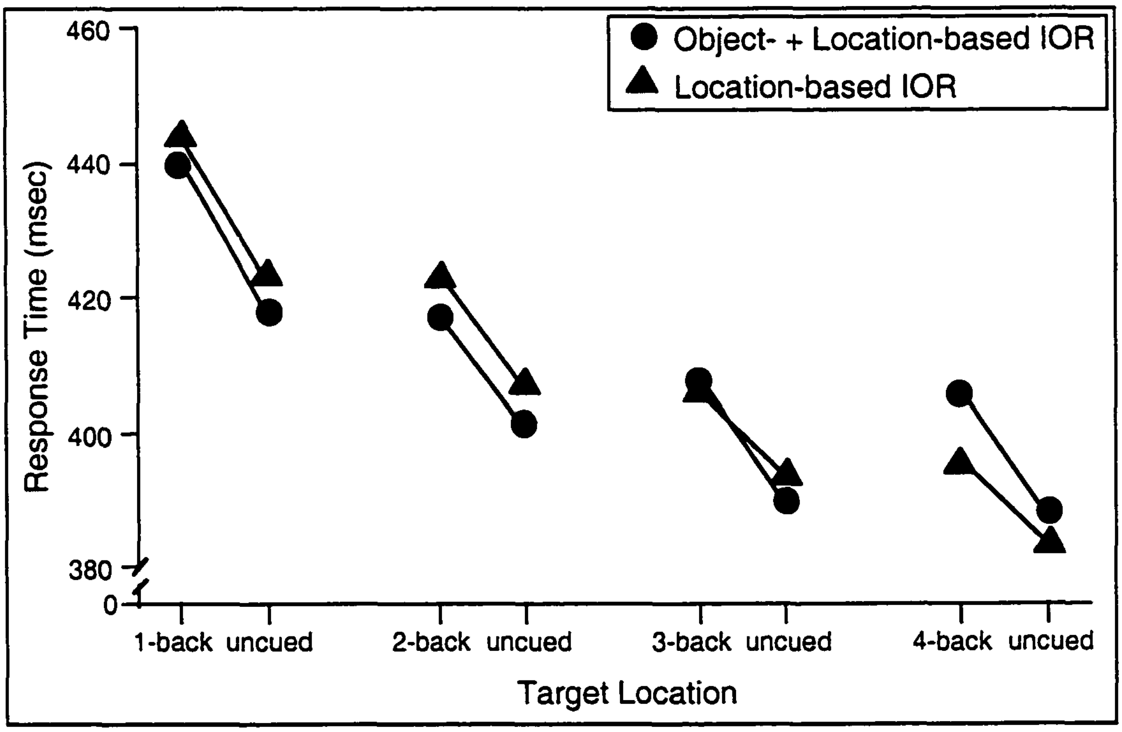

Figure 31. Mean correct RT for object-based plus location-based IOR (placeholders-present) and location-based IOR (placeholders-absent) as a function of target location in Experiment 14.

Cued two-back trials

The main effect of paradigm was again not significant, F < 1. Significant main effects were found for target location, F(1, 24) = 24.26, MSe = 939.51, p < .001, and number of cues, F(2,48) = 36.60, MSe = 861.93, p < .001.

Again, the paradigm x target location interaction was not significant, F < 1. The target location x number of cues interaction was significant, F(2, 48) = 4.04, MSe = 825.27, p < .05, indicating that IOR was greater at a cued two-back location on four-cue trials (30 msec) than on two- or three-cue trials (10 and 11 msec, respectively). The paradigm x number of cues interaction was also significant, F(2, 48) = 4.60, MSe = 709.68, p < .05, indicating a longer RT in the placeholder-absent paradigm for two-cue trials than for placeholder-present two-cue trials. The paradigm x target location x number of cues interaction was again not significant, F(2, 48) = 2.68, MSe = 635.21, p > .07.

Cued three-back trials

A significant main effect was observed for target location, F(1, 24) = 23.28, MSe = 544.92, p < .001. Neither the main effect of paradigm, F < 1, nor number of cues, F(1,24) = 4.11, MSe = 781.18, p > .05, was significant.

None of the interactions was significant (paradigm x target location, F < 1, target location x number of cues, F(1, 24) = 1.23, MSe = 825.27, p > .2, paradigm x number of cues, F < 1, paradigm x target location x number of cues, F(1, 24) = 1.79, MSe = 1159.87, p > .19).

Cued four-back trials

The main effect of target location was significant, $F(1, 24) = 9.28$, $MSe = 661.80$, $p < .01$. Neither the main effect of paradigm nor the paradigm x target location interaction was significant, both $Fs < 1$.

Response accuracy

The mean error rate for the placeholders-present paradigm was 1.15% with errors being false alarms (0.98%), misses (0.15%), and anticipations (0.02%). The mean error rate for the placeholders-absent paradigm was 1.11% with errors being false alarms (0.91%) and misses (0.20%). Error analyses were conducted with a two-factor ANOVA with trial type (one-cue cued one-back, one-cue cued two-back, one-cue uncued etc.) and paradigm (placeholders-present, placeholders-absent) as factors. The ANOVA revealed a significant main effect of trial type, $F(14, 336) = 2.44$, $MSe = .001$, $p < .05$, and a significant interaction between trial type and paradigm , $F(14, 336) = 1.18$, $MSe = .001$, $p < .05$, but no significant main effect of paradigm, $F < 1$. Importantly, there were no differences in errors between cued and uncued locations, $F < 1$. Thus, the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

The prediction for Experiment 14 was that if multiple IOR is composed of both location-based and object-based IOR, then IOR should have been greater in the placeholders-present paradigm than in the placeholders-absent paradigm. Interestingly, although IOR effects were robust for cued one- to four-back locations, IOR effects did not differ for the placeholders-present and placeholders-absent paradigms.

Thus, it would appear that for the multiple IOR reported here, location-based IOR effects are being measured. However, prior to accepting this conclusion, it is important to rule out an alternative explanation. It is possible that the cuing method used was not suitable for measuring object-based effects. Since cuing was accomplished by brightening the outline of an empty placeholder, it could be the argued that an object-based IOR effect developed only around the perimeter of the placeholder. Because the target occurred at the center of the placeholder, it may be the case that object-based IOR would not be operating at that position, and hence, no object-based IOR effects would be found. In Experiment 15, the present study is replicated except that placeholders are solid objects that are cued over their entire surface area.

Experiment 15

Method

Participants

Twenty-five undergraduates participated for course credit. All reported normal or corrected-to-normal vision.

Stimuli, Procedure, and Design

Stimuli, procedure, and design were identical to Experiment 14 with the following exceptions. The stimulus display consisted of light-gray placeholders on a white screen. Cuing was accomplished in the placeholders-present paradigm by drawing a white frame around the light-gray placeholder and an even larger light-gray frame around the white frame with the entire stimulus having the dimensions of 2° x 2°. The visual effect produced was expansion of the placeholder when the frames were added and the contraction back to the original placeholder when the added frames were removed. In the placeholders-absent paradigm, cuing was accomplished with the onset of the light-gray placeholder plus the white and light-gray frames; all of which were removed 200 msec later. The target was a 1.5° x 1.5° dark-gray square.

Results

Data analysis was performed as in Experiment 14. Mean correct RT for placeholders-present and placeholders-absent paradigms as a function of target location is presented in Table 6 and Figure 31.

Table 6. Mean Correct RT (msec) and Mean IOR Effect (msec) for the Placeholder-present and Placeholder-absent Paradigms for Target Location and Number of Cues in Experiment 15.

Target Location	Placeholders-present								Placeholders-absent							
	Number of cues								Number of Cues							
	1		2		3		4		1		2		3		4	
	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR	RT	IOR
uncued	426		390		356		348		439		396		359		351	
1-back	440	15	416	26	373	17	391	43	450	12	415	19	387	28	390	39
2-back			393	3	370	15	376	28			402	6	367	8	368	17
3-back					374	18	364	16					360	1	366	14
4-back							369	21							366	15

Cued one-back trials

The main effect of paradigm was not significant, $F(1, 24) = 1.11$, $MSe = 3720.88$, $p > .3$, indicating that RT did not differ as a function of whether the placeholders were present or absent in the display. A significant main effect was found for target location, $F(1, 24) = 92.18$, $MSe = 657.53$, $p < .001$, indicating a 25 msec IOR effect. The main effect number of cues was also significant, $F(3, 72) = 56.99$, $MSe = 1935.04$, $p < .001$, revealing a warning signal effect.

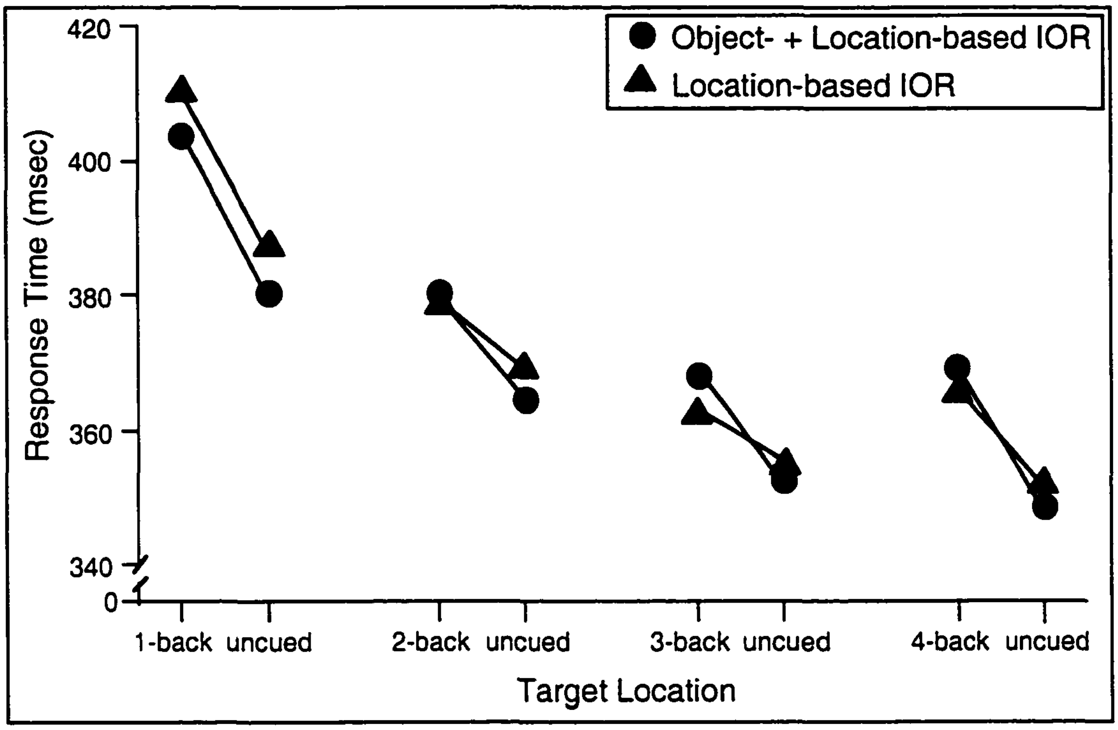

Figure 32. Mean correct RT for object-based plus location-based IOR (placeholders-present) and location-based IOR (placeholders-absent) as a function of target location in Experiment 15.

As in Experiment 14, a significant interaction was not observed for paradigm x target location, F < 1, indicating that total IOR was not different from location-based IOR. A significant interaction was observed between target location x number of cues, F(3, 72) = 4.92, MSe = 679.41, p < .01, indicating that IOR varied as a function of cue number (13, 22, 22, and 40 msec for one-, two-, three-, and four-cue trials respectively). Neither the paradigm x number of cues nor the paradigm x target location x number of cues interaction was significant, F < 1.

Cued two-back trials

The main effect of paradigm was again not significant, F < 1. Significant main effects were again found for target location, F(1, 24) = 24.60, MSe = 506.97, p < .001, and number of cues, F(2,48) = 34.19, MSe = 1065.12, p < .001.

The paradigm x target location interaction was not significant, F < 1. The target location x number of cues interaction was significant, F(2, 48) = 4.94, MSe = 483.137, p < .05, indicating that IOR increased as the number of cues increased (5, 12, and 23 msec on a two-, three-, and four-cue trial, respectively). Neither the paradigm x number of cues interaction, F(2, 48) = 1.38, MSe = 498.79, p > .2, nor the paradigm x target location x number of cues, F < 1, interaction was significant.

Cued three-back trials

A significant main effect was observed for target location, F(1, 24) = 10.37, MSe = 734.63, p < .01. Neither the main effect of paradigm, F < 1, nor number of cues, F(1,24) = 2.42, MSe = 474.55, p > .1, was significant.

None of the interactions was significant (paradigm x target location, F(1, 24) = 1.39, MSe = 779.26, p > .2, target location x number of cues, F < 1, paradigm x number of cues, F < 1, paradigm x target location x number of cues, F < 1).

Cued four-back trials

The main effect of target location was significant, F(1, 24) = 10.89, MSe = 712.79, p < .01. Neither the main effect of paradigm nor the paradigm x target location interaction was significant, both Fs < 1.

Response accuracy

The mean error rate for the placeholders-present paradigm was 0.93% with errors being false alarms (0.82%), misses (0.09%), and anticipations (0.02%). The mean error rate for the placeholders-absent paradigm was 1.44% with errors being false alarms (1.24%) and misses (0.20%). Error analysis was conducted as in Experiment 14. The ANOVA revealed significant main effects of trial type, F(14, 336) = 2.27, MSe = .002, p

< .01, and paradigm, F(1, 24) = 4.41, MSe = .002, p < .05, but no significant interaction between trial type and paradigm, F(14, 336) = 1.15, MSe = .001, p > .03. Importantly, there were no differences in errors between cued and uncued locations, F < 1. Fewer errors occurred for the placeholders-present (0.93%) than for the placeholders-absent (1.44%) paradigm. Thus, the IOR effects observed in the present experiment do not reflect a tradeoff between response speed and response accuracy.

Discussion

The prediction for Experiment 15 was that the IOR should be larger in the placeholders-present than in the placeholders-absent paradigm if multiple IOR had an object-based component in addition to a location-based component. The results of Experiment 15 showed no evidence of an object-based IOR effect despite the manipulation carried out to ensure that the entire placeholder object was cued. Therefore, it can be concluded that multiple IOR is only location-based. This suggests that multiple IOR may facilitate search only in static displays.

General Discussion

Jordan and Tipper (1998) demonstrated recently that both location-based and object-based IOR effects can be found in a static display. The aim in Experiments 14 and 15 was to determine whether multiple IOR effects obtained using the attentional orienting paradigm have both object-based and location-based components. Surprisingly, no evidence of an object-based IOR component was found when the outline of the placeholder object was cued (Experiment 14).

It was possible, however, that the paradigm used was not ideal for generating object-based IOR effects. For instance, when the outline of a placeholder is cued, it may be the case that object-based IOR effects occurred only along perimeter of the placeholder (i.e., the physically cued portion of the object). As a second test for object-based IOR operating in multiple IOR, Experiment 15 was conducted as a replication of Experiment 14 with the exception that the entire placeholder was cued. Once again, multiple IOR effects did not differ across the two types of displays.

Thus, it would appear that multiple IOR is location-based but not object-based. Of course this is not to say that object-based IOR cannot ever be observed concurrently for multiple items. Rather, object-based IOR would not appear to underlie IOR at multiple sites in static displays. It is possible, for instance, that IOR for multiple objects might be observed by modifying the moving object paradigm that has been applied successfully by Tipper and colleagues in their studies of object-based IOR (Tipper, et al., 1991; Tipper, et al., 1997; Tipper & Weaver, 1998; Tipper, et al., 1994; Tipper, Jordan, & Weaver, 1999).

CHAPTER 8: GENERAL DISCUSSION

Over the last fifteen years, a substantial amount of evidence has been collected suggesting that IOR may have a functional role in search. Several investigators (e.g., Klein, 1988; Posner & Cohen, 1984; Posner et al., 1985; Tipper et al., 1994) have argued that the function of inhibition of return is to create a bias to inspect novel locations, thereby facilitating search. Consistent with the idea that IOR facilitates search, research has shown that IOR is coded in environmental rather than retinotopic coordinates (Maylor, 1985; Posner & Cohen, 1984; but see Abrams & Pratt, 2000). Since search generally involves eye movements, coding in environmental coordinates is critical for the maintenance of IOR across saccades. In addition, IOR has been found for saccadic as well as manual detection tasks (Abrams & Dobkin, 1994; Posner et al., 1985; Reuter-Lorenz et al.; Vaughan, 1984). Another feature of IOR that makes it suitable as a search facilitator is that it is found for complex discrimination tasks (Danziger et al, 1998; Pratt, 1996; Pratt, 1996; Pratt et al, 1997; Pratt & Abrams, 1999), as well as for simple detection tasks (Maylor, 1985; Posner & Cohen, 1984). This finding is important because natural searches rarely involve merely detecting the onset of a target item. Furthermore, it demonstrates that IOR is not simply a motor bias against responding and it implies that IOR has an attentional component. Importantly, IOR has also been found at multiple locations in search (Danziger et al., 1998). If IOR could not occur at more than one location in a search, then it could hardly be considered a search facilitator. IOR has also been found for objects as well as for locations (Tipper et al, 1991;Tipper et al, 1994;Tipper & Weaver, 1998). Object-based IOR is necessary in a dynamic world where search often involves mobile objects. And finally, IOR has been inferred with the finding that probe-detection RT is longer at previously searched locations following a visual search task (Klein, 1988; Klein & MacInnes, 1999; Müller & von Mühlenen, in press).

The experiments reported in this thesis provide further support to the view that IOR is a facilitator of visual search. In the preceding chapters, the properties and characteristics of inhibition of return were investigated with a particular emphasis on characteristics that would be important for search. To this end, the first issue addressed in the thesis was whether IOR operates by inhibiting the return of attention to a cued location, by facilitating attention at an uncued location, or both. Although IOR is generally considered to reflect the former, Pratt et al. (1999) recently provided preliminary evidence that IOR operates via a facilitatory effect at the uncued location opposite of the cued location. They suggested that this facilitatory effect at the uncued location is the primary component underlying IOR with a small amount of inhibition at the cued location being a secondary component, and hence playing a relatively minor role. Therefore, it was critical to determine first whether the process underlying IOR was inhibitory or facilitatory in nature. In addition to providing important information about the phenomenon of IOR, determining the nature of the IOR effect was also critical for designing paradigms for the subsequent multiple IOR experiments.

The experiments conducted in Chapter 3 were designed to investigate Pratt et al.'s (1999) attentional momentum hypothesis which suggests that when attention is moved along a path, it has a preference to continue moving in that direction. When a peripheral cue is followed by a central fixation cue, a path of momentum is generated which results in a facilitatory effect at the uncued location opposite to the cued peripheral location. Experiment 1 was designed to determine the boundary conditions of attentional momentum by manipulating the temporal relation between the peripheral cue and the central fixation cue. This manipulation was intended to modulate attentional shifts from the cued peripheral location back to center. Interestingly, robust IOR was observed in the absence of a momentum effect. To rule out the possibility that the cue duration manipulation interfered with the generation of a momentum effect, a second experiment was conducted. Experiment 2 differed from Experiment 1 only in that the fixation stimulus was not brightened. Although a momentum effect was present here, it was considerably weaker than the IOR effect, not present for all cue-target directions, and significant for only a few observers. In a final attempt to ensure that the effect observed in Experiment 2 was the same effect reported by Pratt et al., Experiment 3 was conducted. Once again, a momentum effect was observed but, as in Experiment 2, it was a limited effect restricted to a few observers. Thus, the experiments reported in Chapter 3 determined that IOR results from an inhibitory process operating at the cued location. The facilitatory effect that can accompany the IOR was deemed to be weak and unreliable, in contrast to the robust and reliable IOR effect. This result allowed for the conclusion that the facilitatory effect at the uncued location opposite to the cued location does not play a role in the IOR effect.

This finding is consistent with work done by Posner and Cohen (1984) and Tipper et al. (1994). In Experiment 2 of their seminal investigation of IOR, Posner and Cohen (1984) considered that IOR might reflect both inhibitory and facilitatory processes. However, when a single location was cued, no differences in RT were found for the three uncued locations. Although Tipper et al. (1994) were not investigating facilitatory effects in their object-based IOR experiment, in that experiment, there were also no differences in RT for the uncued locations. The results from the experiments reported in Chapter 3 taken together with the Posner and Cohen (1984) and Tipper et al.'s (1994) results provide compelling evidence that IOR results from inhibition operating at a cued location.

Having established that IOR is inhibitory in nature, the remainder of the experiments in Chapters 4 through 7 were aimed at determining the properties and boundary conditions of multiple IOR. In Chapter 4, the Danziger et al. (1998) hypothesis suggesting that multiple IOR occurs when attention is directed to each cued location was tested. Their hypothesis was based on the observation that multiple IOR could be found at noncontiguous cued locations when observers did not know the number of cues that would precede target onset. They suggested that under these circumstances, observers were forced to attend all peripheral onsets to determine whether the onset event was a cue or a target. By attending cue onsets, IOR was established at all cued locations. Furthermore, they argued that when observers knew the number of cues preceding target onset and, therefore, did not have to attend peripheral onsets, multiple IOR would not be found.

In Experiment 4, this hypothesis was tested by having observers participate in two sessions. In the random session, Danziger et al.'s (1998) Experiment 1 was replicated where the number of cues preceding target onset varied from trial to trial. The prediction here, of course, was that multiple IOR would occur. In the blocked session, the number of cues preceding target onset was fixed across a block of trials. The prediction here was that multiple IOR would not occur. In support of the Danziger hypothesis, multiple IOR was found in the random session. However, contrary to their hypothesis, multiple IOR was also found in the blocked session. Thus, it appeared that multiple IOR occurred whether observers needed to attend peripheral onsets (i.e., in the random session) or did not need to attend peripheral onsets (i.e., the blocked session) .

Prior to accepting the conclusion that multiple IOR is not dependent on attending peripheral onsets, Experiment 5 tested an alternative explanation. What if observers were attending peripheral onsets in the blocked session to track the number of cues to better prepare for target onset? Then attention would have gone to the cued locations albeit for a different purpose than in the random session where attention was necessary to discriminate a cue event from a target event. To test this possibility, a centrally-located number that enumerated peripheral onset events was introduced. Results revealed that, as predicted, multiple IOR occurred in the random session because here the central number provided no information about target onset and observers still had to distinguish between a cue and target event. Importantly, in the blocked experiment, multiple IOR did not occur because the information that required observers to attend to peripheral onsets in the previous experiment (i.e., tracking of cues) was now provided at the central location. This finding provides strong support for the Danziger et al. hypothesis. That is, when observers attend peripheral onsets, multiple IOR occurs at noncontiguous cued locations.

As a final test of the role of attention in multiple IOR, Experiment 6 examined attentional effects at a short cue-target interval. If IOR does indeed result when attention is committed to a cued location, then a facilitatory effect (i.e., shorter RT at a cued than at an uncued location) should be observed at cue-target intervals of less than 150 msec since this result is generally considered to reflect attentional allocation to that cued location. The multiple IOR paradigm was modified to incorporate a short cue-target SOA to test for a facilitatory effect while retaining long cue-cue SOAs to test for inhibitory effects. The finding of a facilitatory effect at a short SOA (i.e., at a cued one-back location) when one, two, or three cues occurred prior to target onset, coupled with the finding of an IOR effect at a long SOA (i.e., at a cued two- and three-back location) confirmed that attention is committed to peripheral onsets when multiple IOR occurs.

The conclusions drawn in Chapter 4 support the position that multiple IOR is observed when attention needs to be committed to the noncontiguous cued locations, and it is absent when attention does not need to be committed to the cued locations. When cued locations cannot be grouped, and attention must be committed to the cued locations (e.g., to discriminate a cue onset from a target onset), then multiple IOR is observed. On the other hand, when the cued locations cannot be grouped and attention does not need to be committed to the cued locations, then multiple IOR is not observed as was the case in the blocked session in Experiment 5 where centrally presented numbers allowed observers to track cues. This research meshes very well with Abrams and Pratt's (1996) study.

They reported that if multiple cued locations are contiguous, they can be grouped together, and they can be inhibited together under a single broad area of inhibition. They also reported that if the cued locations cannot be grouped together then multiple IOR does not occur. This conclusion supports the view of Tipper et al. (1996) that attentional orienting to form IOR at multiple locations is part of a flexible biological system and as such, it is under the control of the observer.

The studies reported in Chapter 5 investigated boundary conditions of multiple IOR such as the number of locations that can be inhibited in a search and the factors affecting the decline in magnitude of IOR across cued back locations. Two findings from Experiment 7 were notable. One, it was determined that IOR could co-occur reliably at up to five, (possibly six) locations, and two, IOR declined in a linear fashion across cued back locations from the most recently cued location to the least recently cued location.

To determine what factor(s) underlie the monotonic decline of IOR, Experiments 8 - 10 were conducted. Three accounts of which processes might give rise to the monotonic function of IOR were considered. First, it could be that the inhibitory tags simply decays with time. Second, it could be that the addition of cued locations creates an attentional priority queue where the most recently cued location has the maximum amount of inhibition and the least attentional priority. Two models were proposed with a decay or reduction in inhibition playing a role in both accounts. And third, it could be that locations are tagged in an all-or-none manner as championed by the FINST hypothesis. Although the FINST model cannot be directly tested, the role of decay and the addition of cued locations were testable.

In Experiment 8, the contribution of decay in the monotonic function of multiple IOR was tested by holding the number of cues constant and varying the time between stimulus onsets. If the IOR effect decays, then the expected result would be smaller IOR effects at longer cue-target SOAs (i.e., a significant target location x SOA interaction). There were several important findings in this experiment. First, SOAs that are sufficient to generate single IOR (i.e., 300 and 400 msec SOAs) were insufficient to generate typical multiple IOR effects. The multiple IOR effects were smaller and did not show the characteristic monotonic function observed in Experiment 7. Second, it appeared that IOR effects may decay at longer SOAs (i.e., 800 msec or more). However, this possibility had to be tested further in Experiment 10 because an interaction between target location and SOA was not found. And third, Experiment 8 confirmed the finding in Experiment 7 that IOR can be held concurrently at five locations.

In Experiment 9, the contribution of additional cued locations to the monotonic function of IOR was tested by varying the number of cues but holding the time interval between the onset of the first cue and the onset of the target constant. There were several important results in this experiment. First, the addition of cued locations appeared to be a factor underlying the monotonic function of multiple IOR. Specifically, the results were best accounted for by the priority queue B hypothesis which proposed that IOR increases for each successive cue. This conclusion was based on the finding that IOR appeared to be relatively consistent for the first cued location, regardless of the number of intervening cues. It is important to note, however, that accepting the addition of cued locations as the factor underlying the monotonic function of IOR was contingent on the assumption that IOR effects do not begin to decay until the capacity limit of the queue is exceeded. This premise was tested further in Experiment 10. Second, IOR effects were most robust and showed the characteristic monotonic function at SOAs of approximately 600 msec.

Experiment 10 was conducted to clarify the role of temporal decay in the monotonic function of multiple IOR which would in turn clarify the role of addition of cued locations in the monotonic function of multiple IOR. Specifically, the questions asked were whether (a) the apparent decay of the IOR effect observed in Experiment 8 at a longer SOA was real and (b) IOR effects increased with the addition of each cued location as suggested in Experiment 9. The results of Experiment 10 determined that the IOR effect does in fact undergo temporal decay at longer SOAs. Furthermore, it was revealed that the addition of cued locations has an impact on the linear decline of IOR at SOAs of less than 750 msec. IOR effects do not increase with the addition of cued locations beyond this range. Beyond this range, the IOR effect peaks and then begin to decay. In addition, it appears that the development of maximum IOR effects may depend on parameter settings (e.g., SOA) that are specific to each experiment. Further investigation of this issue is warranted. These findings are important because they define the boundary conditions of IOR which are, in turn, informative with respect to designing improved multiple IOR paradigms. Another question that remains to be answered is whether the limit on the number of inhibited locations is a function of the number of locations in the display. For instance, in a 10 location paradigm, would IOR effects co-occur reliably at more than five locations or is five inhibited locations an immutable limit?

The findings that multiple IOR can co-occur reliably at least at five locations and that the effect decays over time have provided important supportive evidence of the role of IOR as a facilitator of efficient search. However, research examining the role of IOR in search has come from two experimental paradigms, both of which have limitations. The majority of IOR experiments that have been conducted involve using a variation of the attentional orienting paradigm in which a small number of placeholders (e.g., typically two to four) occupy an otherwise sparse field. One or more placeholders are cued and then a target item is abruptly onset. The task is to detect or discriminate the target as quickly as possible. The principal benefit of this paradigm is that the path of attention can be traced. Therefore, the pattern of IOR effects can be examined and compared at the various cued locations to determine the operating characteristics of IOR. A severe limitation of this paradigm is that natural searches are not that simplistic. They are typically more complex than requiring the detection or discrimination of a single abrupt target onset in a relatively sparse visual field.

The visual search paradigm has also been used to examine the role of IOR in search. The principal benefit of this paradigm is that it better reflects the type of search more likely to be encountered on a day-to-day basis where the target is situated among nontarget items and search is conducted volitionally. Severe limitations of this paradigm include that IOR can only be inferred since it is not known where attention has been or when it went there. Thus, there is a gap in the literature connecting the IOR effects generated with an attentional orienting paradigm to a more typical and complex search task that is representative of visual search outside the laboratory setting.

In Chapter 6, the attentional orienting paradigm and a traditional visual search paradigm were coupled to determine whether the IOR obtained with the attentional orienting paradigm affects a visual search task. In Experiment 11, it was revealed that when a difficult serial search display was onset following the cuing procedure, IOR was found at all cued locations. The pattern of IOR effects was similar to the pattern observed in the preceding experiments. That is, IOR was strongest at the most recently cued location and declined linearly to the least recently cued location. In Experiment 12, where an easy parallel search display was onset following the cuing procedure, IOR was again found at all cued locations. However, the magnitude of the IOR effect was smaller at all cued locations than for the serial search. This finding supports the idea that IOR is of even greater benefit when search is more difficult which is consistent with the impact that a facilitator of search should have. Although Experiments 11 and 12 cannot provide conclusive evidence that the IOR obtained with an attentional orienting paradigm is generated in an everyday visual search, when taken together with the results from previous IOR investigations, they lend support to the hypothesis that IOR plays an important role in search. Furthermore, the results of the present study suggested that IOR might have an object-based component since IOR was obtained in Experiments 11 and 12 when the search display was revealed by offsetting elements of the placeholders and IOR was not obtained in the pilot experiment when the search display was abruptly onset over the placeholders.

Chapter 7 followed up on the hypothesis that multiple IOR might have an object-based component. In Experiments 14 and 15, IOR effects were compared across two display types, one was expected to generate location-based plus object-based IOR and the other was expected to generate location-based IOR only. The experimental design was based on that of Jordan and Tipper (1998) who found a small location-based IOR effect when a target was presented in an empty location in the field that had previously cued. Based on their findings when placeholders were present, it was expected that both object- and location-based IOR would be generated. When placeholders were not present and hence only the location was cued, it was expected that only location-based IOR would be generated. Surprisingly, in Experiment 14, multiple IOR did not differ across the two display types. This finding was replicated in Experiment 15 when the entire region occupied by the placeholder was cued. These results contrast with Jordan and Tipper's finding that a larger object-based plus location-based IOR effect was found when a target was presented in an previously cued placeholder. Thus, it would appear that multiple IOR is location-based but not object-based.

Future Research

IOR has been investigated in a number of different ways with a particular emphasis on what characteristics are necessary for facilitating search. Many questions remain open in at least three major areas, namely (a) what components contribute to the multiple IOR effect, (b) whether the characteristics of single IOR hold for multiple IOR, and (c) what neural substrates underlying multiple IOR.

Components of multiple IOR

One area of investigation must consider whether the IOR effect has an attentional component, a motoric component, or both. Recall that in several studies, including Experiment 5, a small IOR effect occurred at a cued one-back location when attention did not need to be committed to a cued peripheral location. Two possible accounts of this result were suggested. First, the small cued one-back IOR effect may be a motoric and not an attentional effect. The second possibility is that a small amount of attention was captured by the peripheral cue onset. If this is the case, then IOR would only have an attentional component. However, previous research demonstrated that an IOR effect can be produced by either attentional orienting or motor activation to the cued location. Future research will determine if a motor component contributes to the IOR effect and under what circumstances it operates.

The experiments reported in Chapter 7 demonstrated that multiple IOR is location-based but not object-based. It is important to note that this conclusion holds for static displays only. It is possible that object-based IOR effects can be generated only when objects move. Therefore, a stronger test based on moving objects out of a cued location is required to determine whether an object-based effect occurs for multiple IOR.

Single IOR versus multiple IOR

A second area of investigation involves determining whether the characteristics observed for single IOR hold for multiple IOR. In fact, many of the questions initially raised for single IOR must now be asked about multiple IOR. For instance, is multiple IOR coded in environmental or retinotopic coordinates? Can multiple IOR survive eye movements? Are there any differences observed in IOR and multiple IOR when attention is deployed endogenously versus exogenously?

Neural substrates of multiple IOR

A third area of investigation involves determining the neural substrates of multiple IOR. Previous research has established a link between the superior colliculus and the generation of IOR. It is likely that multiple IOR is generated in the same manner but it is unlikely that the SC "holds" the memory for the multiple locations that have been cued. Spatial working memory may be critical to holding inhibited locations. One hypothesis to be tested is that once IOR is generated via the SC, is the right parietal lobe is involved in maintaining inhibition at the cued location? Answering these questions is important to establish a firm link between IOR and its purported function in search.

Conclusions

In conclusion, there is a large amount of accumulating evidence supporting the role of IOR as a facilitator of search. This thesis has added to this body of knowledge by demonstrating that IOR is an inhibitory effect that operates at multiple attended/cued locations. Furthermore, multiple IOR is attentional in nature and it can co-occur reliably at up to five locations in a search. Multiple IOR effects are affected by both the addition of cued locations and temporal decay of the inhibitory tags that produce a linear decline in multiple IOR across cued back locations. Importantly, the multiple IOR generated with an attentional orienting paradigm transfers to a visual search paradigm in which a target appears among heterogeneous and homogenous distractors. And finally, multiple IOR generated in static situations appears to be location-based but not object-based. These properties of IOR are consistent with the expected properties of a search facilitator. Further research efforts are necessary in order to establish the boundary conditions and neural correlates of multiple IOR.

REFERENCES

Abrams, R. A., & Dobkin, R. S. (1994a). The gap effect and inhibition of return: Interactive effects of eye movement latencies. Experimental Brain Research, 98, 483-487.

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

Abrams, R. A., Christ, S. E., & Smith, C. (1999).Object- and location-based inhibition of return in static and dynamic scenes. Paper presented at the meeting of the Psychonomic Society, Los Angeles, CA.

Abrams, R. A., & Pratt, J. (1996). Spatially diffuse inhibition affects multiple locations: A reply to Tipper, Weaver, and Watson (1996). Journal of Experimental Psychology: Human Perception and Performance, 22, 1294-1298.

Abrams, R. A., & Pratt, J. (2000). Oculocentric coding of inhibited eye movements to recently attended locations. Journal of Experimental Psychology: Human Perception and Performance.

Allport, A. (1989). Visual attention. In M. I. Posner (Ed.), Foundations of cognitive science (pp. 631-682). Cambridge, MA: MIT Press.

Cheal, M., Chastain, G., & Lyon, D. R. (1998). Inhibition of return in visual identification tasks. Visual Cognition, 5, 365-388.

Clohessy, A. B., Posner, M. I., Rothbart, M. K., & Vecera, S. P. (1991). The development of inhibition of return in early infancy. Journal of Cognitive Neuroscience, 3, 345-350.

Danziger, S., Fendrich, R., & Rafal, R. D. (1997). Inhibitory tagging of locations in the blind field of hemianopic patients. Consciousness & Cognition, 6, 291-307.

Danziger, S., & Kingstone, A. (1999). Unmasking the inhibition of return phenomenon. Perception & Psychophysics, 61, 1024-1037.

Danziger, S., Kingstone, A., & Snyder, J. J. (1998). Inhibition of return to successively stimulated locations in a sequential visual search paradigm. Journal of Experimental Psychology: Human Perception and Performance, 24, 1467-1475.

Dorris, M. C., Everling, S., Klein, R., & Munoz, D. P. (1998). Neuronal correlate of inhibition of return (IOR): Visual and motor preparatory signals in the monkey superior colliculus. Poster presented at the meeting of the Society for Neuroscience, Los Angeles, CA.

Dorris, M. C., Taylor, T. L., Klein, R. M., & Munoz, D. P. (1999). Influence of previous visual stimulus or saccade on saccadic reaction times in monkey. Journal of Neurophysiology, 81, 2429-2436.

Duncan, J. (1984). Selective attention and the organization of visual information. Journal of Experimental Psychology: General, 113, 501-517.

Duncan, J., & Humphreys, G. (1992). Beyond the search surface: Visual search and attentional engagement. Journal of Experimental Psychology: Human Perception and Performance, 18, 578-588.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. Psychological Review, 96, 433-458.

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. Journal of Experimental Psychology: General, 123, 161-177.

Egly, R., Rafal, R., Henik, A., & Berger, A. (under review). Reflexive and voluntary covert orienting..

Gibson, B., & Egeth, H. (1994). Inhibition of return to object-based and environment-based locations. Perception & Psychophysics, 55, 323-339.

Handy, T. C., Jha, A. P., & Mangun, G. R. (1999). Promoting novelty in vision: Inhibition of return modulates perceptual level processing. Psychological Science, 10, 157-161.

Hood, B. M., Atkinson, J., & Braddick, O. J. (1998). Selection-for-action and the development of orienting and visual attention. In J. E. Richards (Ed.), Cognitive neuroscience of attention: A developmental perspective (pp. 219-250). Mahwah, NJ: Lawrence Erlbaum Associates.

Horowitz, T., & Wolfe, J. M. (1998). Visual search has no memory. Nature, 394, 575-577.

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. Long & A. Baddeley (Eds.), Attention and performance IX (pp. 187-203). Hillsdale, NJ: LEA.

Jordan, H., & Tipper, S. P. (1998). Object-based inhibition of return in static displays. Psychonomic Bulletin & Review, 5, 504-509.

Kingstone, A., & Pratt, J. (1999). Inhibition of return is composed of attentional and oculomotor processes. Perception & Psychophysics, 61, 1046-1054.

Klein, R. (1988). Inhibitory tagging system facilitates visual search. Nature, 334, 430-431.

Klein, R. M. (2000). Inhibition of return. Trends in Cognitive Sciences, 4, 138-147.

Klein, R. M., Kingstone, A., & Pontefract, A. (1992). Orienting of visual attention. In K. Rayner (Ed.), Eye movements and visual cognition: Scene perception and reading (pp. 46-63). North-Holland: Elseiver Science Publishers.

Klein, R. M., & MacInnes, W. J. (1999). Inhibition of return is a foraging facilitator in visual search. Psychological Science, 10, 346-352.

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, CA: Academic Press.

Kwak, H., & Egeth, H. (1992). Consequences of allocating attention to locations and to other attributes. Perception & Psychophysics, 51, 455-464.

Lupiáñez, J., Milan, E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Perception & Psychophysics, 59, 1241-1254.

Lupiáñez, J., & Milliken, B. (1999). Inhibition of return and the attentional set for integrating versus differentiating information. The Journal of General Psychology, 126, 392-418.

Maylor, E. A. (1985). Facilitatory and inhibitory components of orienting in visual space. In M. I. Posner & O. S. M. Marin (Eds.), Performance and attention XI (pp. 189-207). Hillsdale, NJ: LEA.

McDonald, J. J., Ward, L. M., & Kiehl, K. A. (1999). An event-related brain potential study of inhibition of return. Perception & Psychophysics, 61, 1411-1423.

Müller, H. J., & Rabbitt, P. M. A. (1989). Reflexive and voluntary orienting of visual attention: Time course of activation and resistance to interruption. Journal of Experimental Psychology: Human Perception and Performance, 15, 315-330.

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

Müller, H. J., & von Mühlenen, A. (in press). Probing distractor inhibition in visual search: Inhibition of return. Journal of Experimental Psychology: Human Perception and Performance.

Myers, J. L., & Well, A. D. (1991). Research Design and Statistical Analysis. Hillsdale, NJ: Lawrence Erlbaum Associates.

Pashler, H. E. (1998). The psychology of attention. Cambridge, MA: MIT Press.

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

Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, 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., & Abrams, R. A. (1995). Inhibition of return to successively cued spatial locations. Journal of Experimental Psychology: Human Perception and Performance, 21, 1343-1353.

Pratt, J., & Abrams, R. A. (1999). Inhibition of return in discrimination tasks. Journal of Experimental Psychology: Human Perception and Performance, 25, 229-242.

Pratt, J., Kingstone, A., & Khoe, W. (1997). Inhibition of return in location- and identity-based choice decision tasks. Perception & Psychophysics, 59, 964-971.

Pratt, J., Spalek, T. M., & Bradshaw, F. (1999). The time to detect targets at inhibited and non-inhibited locations: Preliminary evidence for attentional momentum. Journal of Experimental Psychology: Human Perception and Performance, 25, 730-746.

Pylyshyn, Z. (1989). The role of location indexes in spatial perception: A sketch of the FINST spatial-index model. Cognition, 32, 65-97.

Rafal, R., Henik, A., & Smith, J. (1991). Extrageniculate contributions to reflex visual orienting in normal humans: A temporal hemifield advantage. Journal of Cognitive Neuorscience, 3, 322-328.

Rafal, R. D., Calabresi, P. A., Brennan, C. W., & Sciolto, T. K. (1989). Saccade preparation inhibits reorienting to recently attended locations. Journal of Experimental Psychology: Human Perception and Performance, 15, 673-685.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. Psychological Science, 8, 368-373.

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.

Ro, T., & Rafal, R. D. (1999). Components of reflexive visual orienting to moving objects. Perception & Psychophysics, 61, 826-836.

Rodieck, R. W. (1998). The first steps in seeing. Sunderland, MA: Sinauer Associates.

Sapir, A., Soroker, N., Berger, A., & Henik, A. (1999). Inhibition of return in spatial attention: Direct evidence for collicular generation. Nature Neuroscience, 2, 1053-1054.

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

Schmidt, W. C., Fisher, B. D., & Pylyshyn, Z. W. (1998). Multiple location access in vision: Evidence from illusory line motion. Journal of Experimental Psychology: Human Perception and Performance, 24, 505-525.

Takeda, Y., & Yagi, A. (in press). Inhibitory tagging in visual search can be found if search stimuli remain visible. Perception & Psychophysics.

Tanaka, Y., & Shimojo, S. (1996). Location vs. feature: Reaction time reveals dissociation between two visual functions. Vision Research, 36, 2125-2140.

Tassinari, G., Biscaldi, M., Marzi, C. A., & Berlucchi, G. (1989). Ipsilateral inhibition and contralateral facilitation of simple reaction time to non-foveal visual targets from non-informative visual cues. Acta Psychologica, 70, 267-291.

Taylor, T. L., & Klein, R. M. (1998). On the causes and effects of inhibition of return. Psychonomic Bulletin & Review, 5, 625-643.

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., Driver, J., & Weaver, B. (1991). Object-centered inhibition of return of visual attention. Quarterly Journal of Experimental Psychology, 43A, 289-298.

Tipper, S. P., Jordan, H., & Weaver, B. (1999). Scene-based and object-centered inhibition of return: Evidence for dual orienting mechanisms. Perception & Psychophysics, 61, 50-60.

Tipper, S. P., Rafal, R., Reuter-Lorenz. P. A., Starrveldt, Y., Ro, T., Egly, R., Danziger, S., & Weaver, B. (1997). Object-based facilitation and inhibition from visual orienting in the human split-brain. Journal of Experimental Psychology: Human Perception and Performance, 23, 1522-1532.

Tipper, S. P., & Weaver, B. (1998). The medium of attention: Location-based, object-centered, or scene-based? In R. D. Wright (Ed.), Visual attention (pp. 77-107). New York, NY: Oxford University Press.

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.

Tipper, S. P., Weaver, B., & Watson, F. L. (1996). Inhibition of return to successively cued spatial locations: Commentary on Pratt and Abrams (1995). Journal of Experimental Psychology: Human Perception and Performance, 22, 1289-1293.

Treisman, A. (1988). Features and objects: The Fourteenth Bartlett Memorial Lecture. Quarterly Journal of Experimental Psychology, 40A, 201-237.

Treisman, A. (Ed.). (1998). The perception of features and objects. In R. D. Wright (Ed.), Visual attention (pp. 26-54). New York, NY: Oxford University Press.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. Cognitive Psychology, 12, 97-136.

Valenza, E., Simion, F., & Umiltá, C. (1994). Inhibition of return in newborn infants. Infant behavior and development, 17, 293-302.

Vaughan, J. (1984). Saccades directed at previously attended locations in space. In A. G. Gale & F. Johnson (Eds.), Theoretical and applied aspects of eye movement research (pp. 143-150). Amsterdam: North-Holland.

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. Psychological Review, 104, 90-122.

Watson, D. G., & Humphreys, G. W. (1998). Visual marking of moving objects: A role for top-down feature-based inhibition in selection. Journal of Experimental Psychology: Human Perception and Performance, 24, 946-962.

Weaver, B., Lupiáñez, J., & Watson, F. (1998). The effects of practice on object-based, location-based, and static-display inhibition of return. Perception & Psychophysics, 60, 993-1003.

Wolfe, J. M. (1994). Guided search 2.0: A revised model of visual search. Psychonomic Bulletin & Review, 1, 202-238.

Wolfe, J. M. (1998a). Visual search. In H. Pashler (Ed.), Attention (pp. 13-73). Hove, England, UK: Psychology Press/Erlbaum (UK) Taylor & Francis.

Wolfe, J. M. (1998b). What can a million trials tell us about visual search? Psychological Science, 9, 33-39.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the Feature Integration Model for visual search. Journal of Experimental Psychology: Human Perception and Performance, 15, 419-433.

Wolfe, J. M., & Pokorny, C. W. (1990). Inhibitory tagging in visual search: A failure to replicate. Perception & Psychophysics, 48, 357-362.

Wright, R. D., & Richard, C. M. (1996). Inhibition-of-return at multiple locations in visual space. Canadian Journal of Experimental Psychology, 50, 324-327.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. Journal of Experimental Psychology: Human Perception and Performance, 16, 121-134.

Yantis, S., & Jonides, J. (1996). Attentional capture by abrupt onsets: New perceptual objects or visual masking? Journal of Experimental Psychology: Human Perception and Performance, 22, 1505-1513.