Nonspatial Inhibition of Return (IOR) in Attentional Orienting

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A Thesis Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

in

Psychology

May 2009

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Doctor of Philosophy in Psychology

at the Chinese University of Hong Kong in May 2009.

Abstract

Inhibition of return (IOR) has been reported when a target is preceded by an irrelevant stimulus (cue) at the same location: Target detection is slowed, relative to uncued locations. It is suggested that IOR is a general phenomenon that helps to provide a broad sampling of stimuli in the environment. In recent years, however, the generality of the IOR phenomenon has been questioned. Although there is considerable research demonstrating inhibition of cued locations, and a mountain of evidence for inhibition of cued objects, inhibition of cued nonspatial attributes, like color, shape and orientation, has rarely been explicitly demonstrated. Using a paradigm that has shown robust location-based IOR when relatively richer displays are presented, the present thesis addresses three noticeable gaps in the IOR literature relating to nonspatial feature visual search.

First, although there is some evidence suggesting IOR influences nonspatial attribute-based visual search, the effects observed have been small and inconsistent, have not followed the same time course as more standard IOR, and there is some evidence that the effect may depend on presenting a "neutral attractor" between the cue and target. In Experiments 1(1a,1b) and Experiment 2(2a), participants

demonstrated a robust color-, and shape - based inhibitory effect that, unlike previous findings, followed a time course similar to that for location-based IOR. Moreover, the effect does not seem to require the presentation of a neural attractor. Experiment 3 and Experiment 2b demonstrated that less or no attribute-based IOR appeared if the cue and target were less salient. The results showed that if the stimuli offer featural differences that are salient enough, the perceptual system uses them to encode the displays, and IOR can be applied to those features.

Second, the nonspatial-based IOR effect does not seem to be independent of location, as it only occurs when cue and target share not only features, but location. The results suggest that attentional selection can be applied to stimulus properties such as color, shape, and orientation, but that the attentional operations are specified in location-based coordinates. Given location-based IOR appeared in all experiments, repetition of nonspatial features may reflect an additional phenomenon. When the cue and the target do not share location, they can not be the same object, indicating featural IOR is rather object based.

Third, in Experiment 4, 5 and 6, when attribute discrimination tasks were required, the attribute-based IOR was gone. So far, there have been a limited number of studies examing the attribute-based discrimination research, and the results of them are mixed. Our results clearly indicated that the attribute-based inhibitory effect does not generalize to higher mental demanding tasks. We suggested that this type of cuing effects can be considered as different manifestations of attentional capture on non-spatial attributes processing, that is, under attribute-based higher demanding tasks observers allocate attestation to locations, rather than to attributes; hence IOR is predominantly location-based.

To conclude, these findings shed considerable light on IOR: nonspaital attribute-based IOR can be demonstrated under certain conditions, with rich displays, and with enough stimulus salience. Critically, the effect of inhibition directed to an attribute is tied to the location of the prior stimulus. The effect also depends on the difficulty of the target processing (simple detection task vs. discrimination task).

中文摘要

對空間某一靶子進行線索化，隨後對該靶子的反應產生促進作用（反應速度加快），但是，一段時間（通常是 300 毫秒）以後，這種易化作用出現反轉，即易化轉變成抑制作用（反應速度變慢）。這種視覺加工現象被稱之爲返回抑制（Inhibition of Return, IOR）。一般認爲返回抑制是一種普遍現象，利於人們有效的注意和搜索。近年來，一些學者們開始質疑它的普遍性。目前儘管對基於位置的返回抑制的研究已經很多，但是對返回抑制能否發生在非空間的特徵（如顏色，形狀，和朝向等等）的研究很少，結果也很不確定。

本研究使用一種新的範式（Samuel 和 Weiner, 2001）系統考察了非空間特徵的返回抑制現象。除範式效度證實性實驗外，本研究使用了 6 個實驗：（1）證實性實驗成功重複了原實驗結果，證實範式有效可用；（2）實驗一至實驗三使用覺察任務考察顏色、形狀和朝向的返回抑制時間和空間模式，結果發現，非空間返回抑制在較複雜刺激背景條件下，在線索靶子間隔 700 毫秒即可出現，可持續到 3500 毫秒後。但是只有線索和靶子特徵差別顯著情況下，非空間返回抑制才能呈現；並且非空間特徵返回抑制局限在靶子和干擾物“位置同一”的情況下。另外，中間分心物對抑制效應作用不顯著。（3）實驗四至實驗六使用辨別任務，考察顏色、形狀和朝向的返回抑制時間和空間模式。結果發現，任務改變，非空間返回抑制現象消失，只有促進效應存在；典型的基於位置返回抑制任然存在。

本研究首次觀察到非常顯著的非空間返回抑制現象。這種抑制遵從了典型的基於位置的返回抑制時間特徵。研究證實觀察到的抑制現象，不同於特徵重複

盲現象(repetition blindness:RB)。這種返回抑制與位置關係密切。之前的報告不能發現特徵返回抑制，是因爲實驗方法及任務可能不足夠引發這種抑制現象。本研究的理論意義是證實了返回抑制可以在特徵水平發生，支持了返回抑制的普遍性觀點。但是特徵抑制現象跟位置關係非常緊密，本研究認爲在視覺搜索中，特徵抑制基於位置；進一步，特徵抑制具有客體性（object-based）。

Acknowledgements

With most sincere thanks to my mentors. To Agnes S.Chan, my supervisor for providing me with exceptional support and guidance during my Ph.D study tenure. I am deeply appreciative of her ongoing efforts to guide and prepare me as a critical thinker. To John Zhang, and Alan Wong, for providing me with many valuable pieces of advice and helpful comments at critical points during my proposal and thesis preparation.

Special thanks to Arthur G. Samuel, a generous mentor, for committing much time and patience toward my training and academic development. I have been exceedingly fortunate to have worked with him. And further thanks to Juan Lupiáñez, Raymond Klein, Jay Pratt, Jeremy Wolfe and Elizabeth Ann Maylor for their interest, help and useful recommendations during my experiments and my thesis writing. Juan Lupiáñez's insightful comments provided important contributions to the strengthening of this dissertation. I also thank Julie Anne Alvarez of Tulane University, Tracy L. Taylor of Dalhousie University, and Michael D.Dodd of Toronto University (now University of Nebraska – Lincoln) for their help and showing me their important research.

I am grateful to my labmates, especially Sophia, Beth, Teddy and Debbie, who have offered help and emotional support throughout the process of my study. Finally, I would like to thank all my families, especially my mother Xianghui Yang, for their warm support and encouragements. You are all most dear to me!

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Chapter 1: Introduction

What is the attention? As James said, "it is the taking possession of the mind; in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalisation, concentration, of consciousness are of its essence" (James,1890; P403-404). However the environment around us is far too complex, so that usually we can never fully process all the information it provides simultaneously. Selective attention is the consequence of this limitation. This limitation can be observed when under complex conditions, observers are required to determine whether a particular stimulus/event is present in a display, or even to simply respond to the onset of a stimulus/event. Without a special attention mechanism to select and filter input, it is impossible for the observers to perceive what is important and where to respond (James, 1890; Helmholtz, 1910; Broadbent, 1958).

A critical function of our visual system is to efficiently direct attention to features of our environment to determine which stimuli are to be further processed, and which are to be ignored ("Spotlight" metaphor, Norman, 1968). There are two main types of such covert orienting: exogenous and endogenous. "Exogenous" refers to those attention shifts controlled by environmental events (see Nakayama & Mackeben, 1989). For example, in a silent library when a heavy book suddenly drops to the floor, most of the readers' attention will be drawn by this event. By contrast, "endogenous" suggests that attention is under the control of the observer, hence this orienting is determined from within, rather than from the outside events (see Posner, 1980, Duncan, 1984). An example for this is searching for a special friend's face at a party. Exogenous orienting is driven in a bottom-up manner (automatically) while the endogenous one has top-down characteristics. Distinguished from covert orienting, overt orienting means the alignment of peripheral visual receptors with the source of visual input, for example, through saccadic eye movements. In the present thesis we are mainly concerned with covert orienting.

Eriksen and Hoffman (1973) first demonstrated that, no matter whether the attention is shifted endogenously or exogenously, the processing of attended objects/locations is facilitated, relative to other objects/locations. They presented cues at various locations on an otherwise blank screen, and then shortly after, a letter, as a target, would appear at either a cued or uncued location. They found that the observer's reaction time to identify letters appearing at cued locations were faster than responses to letters appearing at uncued locations.

Covert Orienting

Posner et al. (1978) developed a Covert Orienting of Visuospatial Attention Task (COVAT) to measure simple reaction time (RT) in stimulus detecting tasks. To illustrate, the procedure begins with a central fixation cross appearing. There are two boxes located on either side in the periphery. Participants are required to maintain fixation on the central cross throughout the entire testing period. An intertrial interval (ITI), which usually lasts about 1000 to 2000 ms after the presentation of the central fixation cross and peripheral boxes, is included. Next a central "endogenous" arrow cue or a peripheral "exogenous" spatial cue appears. Cues predict (correctly or incorrectly) that a target will appear in a particular location. The task for the participants is to hit a response key as quickly and accurately as possible to the appearance of a target stimulus. Generally, the target follows approximately 50 to 1000 ms after the cue and appears in one of the two peripheral boxes. There exist three possibilities: the cue correctly predicts the location of the target ("valid" situation), incorrectly predicts the location of the target ("invalid" situation), or offers no information as to the likely location of the target ("neutral" or "null" situation). It is known that several factors influence the pattern of RTs in the covert orienting of visual attention tasks. The results (reaction time patterns) are correlated with the type of the cue (endogenous or exogenous) and with the type of information the cue offers (invalid, valid or neutral information). Another critical factor is the time between the onset of the cue and the onset of the target (the stimulus onset asynchrony, or SOA).

Exogenous covert orienting

As to the exogenous covert orienting, it means a cue appears in the periphery, such as a brightening of a box which captures the observers' attention and signals that a target is about to appear in one of the peripheral boxes. According to Cheal and Lyon (1991) and Muller and Findlay (1988), exogenous orienting is more rapid and difficult to inhibit. In addition, it is unaffected by a concurrent task (Jonides, 1981). Another characteristic is that exogenous control is independent of the observer's goals (Posner & Cohen, 1984; Yantis, 1995).

Michael Posner has done seminal and systematic research in this area. Originally, Posner (1978, 1980) thought that external signals did not operate completely reflexively but would only summon attention and eye movements if they were important to the subjects. In his opinion, comparison of exogenous and endogenous control of orienting is difficult for this reason. So, he proposed to compare central and peripheral systems for producing changes in orienting as a model system to observe the interaction of external and internal control. With this reason, in his initial study, the author adopted probabilistic exogenous cues. In detail, "valid" exogenous cues correctly provided information about where the target would appear 80% of the time; "invalid" peripheral cues wrongly directed attention to the incorrect location 20% of the time. While the "neutral" cues provided temporal but not spatial information about the target's probable location, the "null" cues did not provide spatial or temporal information regarding the target's appearing (see Figure 1). Posner et al. (1978) found that RTs to targets following valid cues were faster than those following no cues, and RTs to targets following invalid cues were slower than those following no cues. This result pattern, along with similar results from the probabilistic endogenous cues experiments led to their well-know theory which assumed attention is "a spotlight that enhances the efficiency of detection of events within its beam" (Posner et al. 1980).

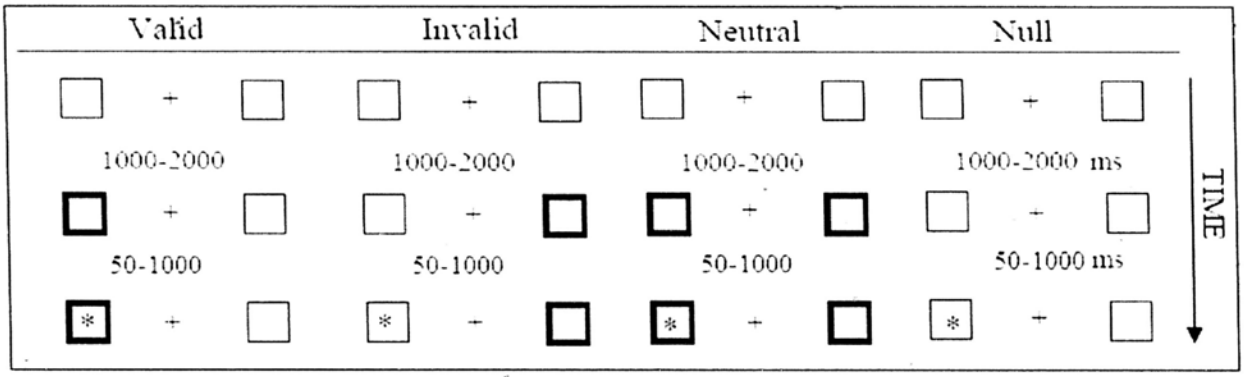

Figure 1. Exogenous cue conditions. First row stands for the fixation display. The second row is the cue onset display(four conditions: Valid, Invalid, Neutral and Null). The final row is the target display.

At about the same time, Jonides (1981) systematically tested the hypothesis that shifts of attention can be mediated by automatic as well as voluntary control. He examined differences between cues on three criteria for comparing automatic versus nonautomatic processes: capacity demands, resistance to suppression, and sensitivity to changes in expectancy. Specifically, he considered three explanation for automatic (exogenous) processing: firstly, the peripheral cue is more precise in its localization by dint of its position in the display; secondly, compared to a central cue, a peripheral cue requires less "deep" encoding and thirdly, a peripheral cue effectively captures attention because it exploits a predisposition of the visual system to be especially sensitive to salient discontinuities off the fovea. Hence, exogenous cues activate attention automatically, that is, without probabilistic information. To conclude, the cues no longer are informative as to the likely (or unlikely) location of the target. Given this speculation, "valid" and "invalid" cues mean less in the non-probabilistic experiment type. When the target appears in the same location as the cue, we term it as a "cued" situation; when the target appears in the location opposite to the cue, we call it an "uncued" situation. Considering the exogenous cues do not have to be probabilistic to elicit attention, Posner later used non-probabilistic exogenous cues too, though he initially employed probabilistic exogenous cues.

Now it is known that this type of cueing is linked to three areas: Posterior parietal lobe, the lateral pulvinar nucleus of the postereolateral thalamus and the superior colliculus (c.f. Posner & Peterson, 1990). The current literature consistently suggests that the posterior system controls the "bottom-up" aspects of attention associated with saccadic eye movements and the shifting of attention from one stimulus location to another (e.g. Posner & Dehaene, 1994).

Endogenous covert orienting

As we mentioned above, covert visual orienting can be controlled exogenously and endogenously. Endogenous covert orienting refers to an internally driven process that is characterized by a strategic decision on the part of the observer to shift attention to a particular location or object in the visual scene (Jonides, 1981, Muller & Humphreys, 1991; Warner, Juola, & Koshino, 1990; Danziger & Kingstone, 1999).

In Posner and Cohen (1984), one display manipulation is: first a symbolic cue (a central arrow either valid or invalid for the upcoming target location) appeared, after certain time followed by a target to be responded to (in a peripheral location). In experimental paradigms, endogenous cues (e.g. an arrow stimulus) usually appear at a central fixation point. Endogenous covert orienting is accomplished via task demands, stimulus probabilities, symbolic cues that encourage top-down allocation of attentional resources to a location, or to an object, or to the development of a nonspatial expectancy.

In detail, the centrally presented arrow indicates which peripheral location the target stimulus (an asterisk) is likely to appear (see Figure 2). The probability[1] is above than chance (usually from 70% to 90%). In Figure 2, the "valid cue" means an arrow correctly predicts the target location with 80% probability, while "invalid cue" stands for the remaining 20% prediction of the time. The "neutral cue", the arrow with two heads at both ends, can offer no predicative information. The "Null" condition means no arrow is presented; only the fixation cross remains.

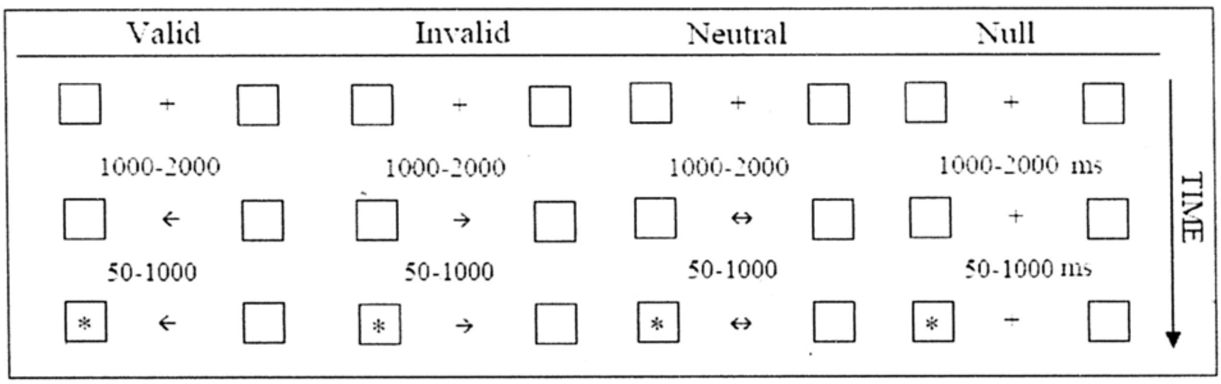

Figure 2. Endogenous cue conditions. First row stands for the fixation display. The second row is the cue onset display (four conditions: Valid, Invalid, Neutral and Null). The final row is the target display.

Posner, Nissen and Ogden (1978) examined the endogenous control of covert orienting. Their results indicated that in comparison to RTs following "neutral cues", RTs to targets following valid cues were faster, while RTs to targets following invalid cues were slower (the "Validity effect", Rafal & Posner, 1987). In particular, Posner et al.(1978) assumed that the facilitatory effect is a "benefit" of the valid cues and the inhibitory effect is a "cost" of the invalid cues. Hence this paradigm was termed a

[1] Probability, or chance, is a way of expressing knowledge or belief that an event will occur or has occurred. When cue accuracy to target location is between 51 and 99%, the condition is termed "probabilistic".

cost-benefit paradigm. At that time, cost-benefit analysis became quite popular as a tool to diagnose preparatory process in cognition.

However, after reviewing the technique and the assumptions underlying the cost-benefit approach, Jonides and Mack (1984) suggested some pitfalls that are encountered in actually implementing this technique in various experimental contexts. Cost-benefit analysis relies on the same rationale as Donders' (1969) subtraction method. But the rationale hinges on a critical assumption, that is, the neutral and informative cues must be identical with respect to all their effects except that of information specific to the target. Clearly, the implication fails to be satisfied in Posner et al.(1978)'s since the "neutral cue" and "Null" situation did not provide temporal information about where the target would appear. In fact, the difference between RTs to valid and neutral or null cues is not always reliable, but the difference in RTs to valid versus invalid cues is usually robust. Because of this, recent researchers usually use only valid and invalid cues in the endogenous paradigm.

Endogenous visual orienting belongs to a "top-down" type of attention. It is related to executive function, including shifting attention voluntarily, maintaining mental sets, error monitoring, etc. Posner and his colleague reported that the endogenous control of covert orienting is associated with the "anterior attention system", which is located in the anterior cingulate and basal ganglia (Posner & Dehaene, 1994).

It is worthy to note that exogenous and endogenous mechanisms usually interact during visual search, though they may be qualitatively different in the processes.

Inhibition of Return: an inhibitory after-effect

Using non-probabilistic exogenous cues (the target was equally likely to appear in the cued or uncued location), Posner and Cohen. (1984) discovered a very important phenomenon in which a precue to a particular location in the visual field appeared to inhibit responses to that location rather than to facilitate them. This discovery extensively influenced later vision research. With a student's respectful feelings, Klein (2000) wrote as below:

> *"It is a testament to the scientific ingenuity and rigor of its authors that so much of what we know about IOR was first demonstrated in Posner and Cohen's seminal paper, and so many questions that have subsequently been pursued were anticipated there".* (Klein, 2000; p139)

In one experiment of Posner and Cohen (1984)'s seminal paper, subjects faced three boxes – one was at the centre, and the other two located on either side in the periphery. At first, one of the peripheral boxes was brightened for 150 ms, as a visual cue. Then as a target, a small dot emerged in the center of one of the boxes 0-500 ms following the onset of the cue. The participants were required to respond once the target appeared. This is the cue-target paradigm (see Figure 3). The target appeared at the central box with a probability of 0.6 and at the each of the peripheral boxes with probability 0.1. Catch trials were inserted with a probability of 0.2 where no target appeared. Posner and Cohen found that when stimulus onset asynchronies (SOAs) were greater than 300 ms, people reacted more slowly to targets at previously cued locations than to targets at novel locations.

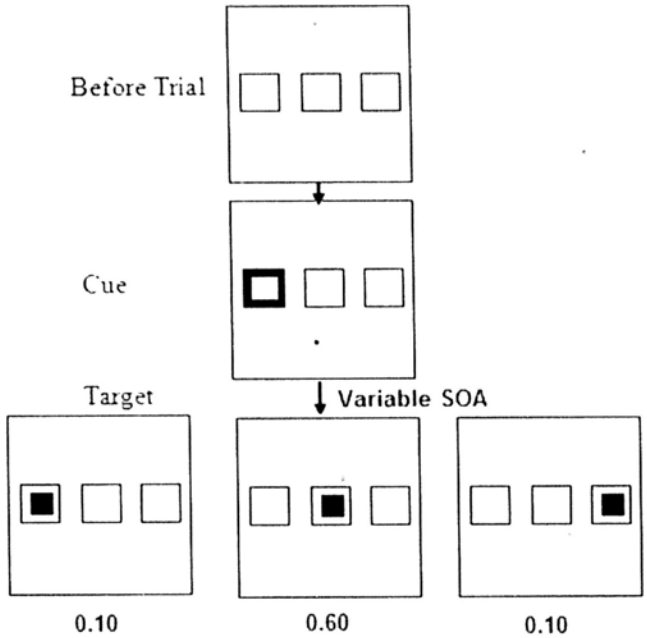

Figure 3. The sequence of events in a typical trial demonstrating IOR. First, the top panel appears and the subject is required to fixate at central box. A brightening of the outline of one peripheral box initiates a trial (the second panel). After an interval, a small but bright target emerges in the center of one of the boxes to which a response is required.

Actually, at short SOAs (before 250 ms), RTs were facilitated to targets that appeared at the same versus a different location as the cue. So, the cueing effect is biphasic, first with a facilitatory component, followed by an inhibitory component (the pattern is illustrated in Figure 4). When the cue-target SOA is less than 250 ms, the facilitative effect of the cue for targets at the cued vs. uncued locations has been attributed to the benefit of attention, reflecting exogenous capture of attention by the cue. When the SOA is more than 300 ms, the results illustrate the cost of attention, reflecting the effect of endogenously maintaining attentional resources at the central location (please be reminded, the target had a 60% probability of appearing in the central location). The delay of responding, were later labeled inhibition of return (IOR) by Posner, Rafal, Choate, & Vaughan (1985)[2].

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[2] The same effect has been termed "inhibitory aftereffect" by Tassinari et al. (1987)

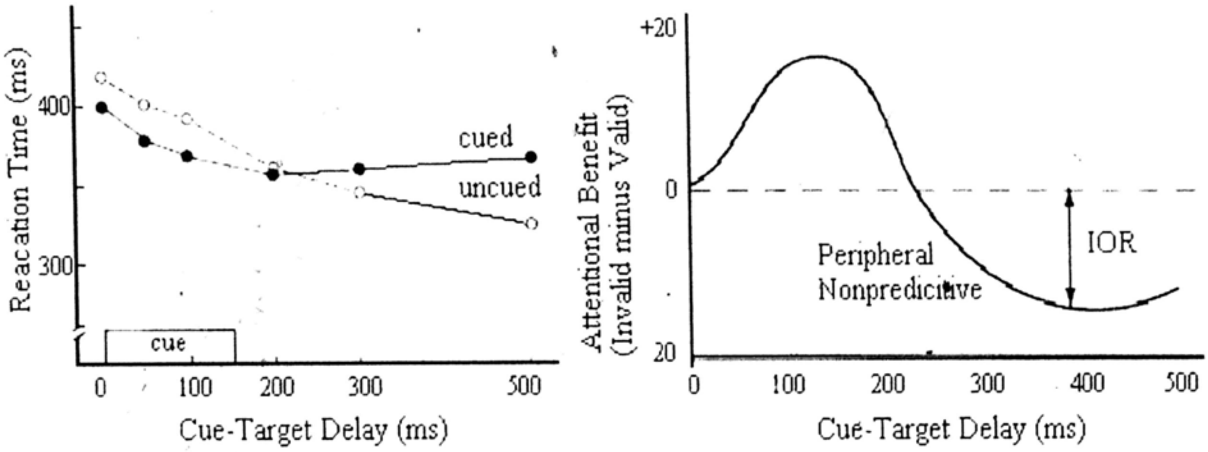

Figure 4. Left panel: The data from such an experiment, by Posner and Cohen. Filled circles: responses to cued targets; empty circles: responses to uncued targets (Adapted from Posner & Cohen, 1984); *Right panel:* a graph plots the difference between response times to uncued and cued trials, using a hypothetical continuous attentional response. Before about 225 ms, the valid cuing resulted in attentional benefits, followed by a period of inhibitory effect (IOR) after that time point.

When using four peripheral boxes, Posner and Cohen found the inhibitory effect still existed. This ruled out an explanation based on the fact that only two peripheral positions were used as possible target positions in the original experiment (e.g. one may argue that participants can guess the target would occur at the other position if they failed to find the target at the cued location shortly after the cue appeared). In another experiment, Posner and Cohen (1984) used a symbolic cue (arrow) and found the facilitative effect but no inhibitory effect. This result means that the inhibition may depend primarily upon sensory information, rather than attentional orienting (this remains a debate, see e.g. Rafal et al., 1989).

Posner and Cohen reported that the biphasic pattern of results can also be obtained with peripheral cues that dim rather than brighten. Collectively, the results indicate that the early facilitatory effect does not depend on luminance summation of cue and target. In Ponser and Cohen (1984), the probability distribution encouraged the subjects to endogenously maintain attentional resources at the central location. Further studies (for example, Possamai,1986) found a similar biphasic effect when the target probabilities were equal across the locations. Under these conditions, it is likely that subjects usually endogenously maintain their attention centrally since the target appears in all three locations equally often, and maintain attention at the central location would presumably entail the least effort.

Following this initial study, Maylor and Hockey (1985) designed classic experiments, eliminating possible explanations in terms of response inhibition, masking, and sensory habituation. They found that IOR occurs whether or not the first stimulus requires a response, and that it lasts at least a second. In addition, the inhibitory effect affects not only the originally stimulated location but also nearby locations. Hence, IOR is specified in environmental coordinates, and occurs both in the periphery and at the fovea.

Notably, the paradigm Maylor and Hockey (1985) used is a target-target one, which is different from the cue-target format. To illustrate, the "cue" in this trial was the preceding target and the response-stimulus interval was manipulated from trial to trial. Since the inhibitory effect appeared, the authors speculated that IOR is not dependent on the use of a cue-target paradigm.

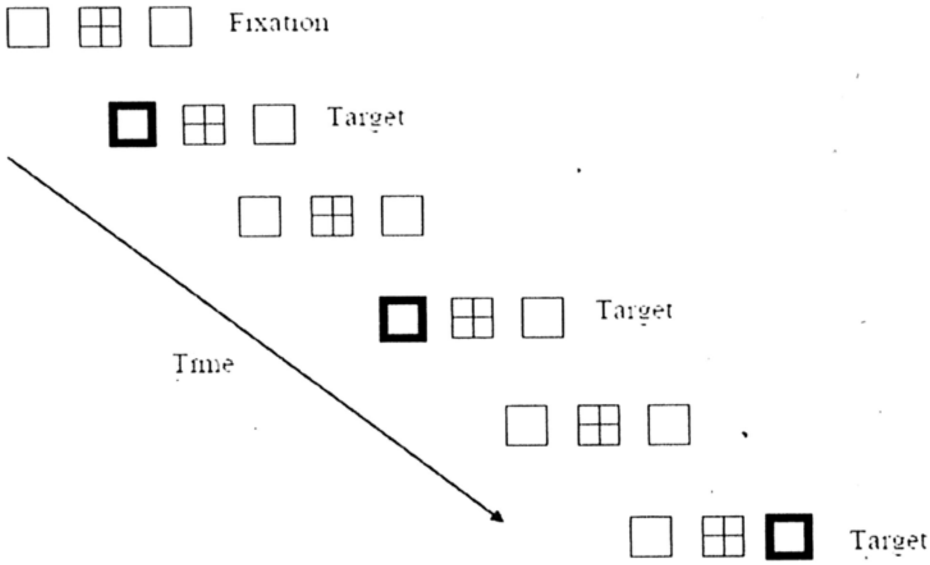

Figure 5. Sequence of events in a typical target-target paradigm. The stimuli are white on a black background. Firstly, subjects are required to fixate at central box (first panel). Then a brightening of the outline of one peripheral box initiates a trial (second panel). This is the first target. After an interval, one of the three boxes shows brightness (a target, but also a cue to the next target trial). Similarly, after a certain interval, another target appears for next trial.

Many studies have replicated Posner and Cohen's original finding of a biphasic pattern of an early repetition advantage followed by a later repetition disadvantage (see Samuel & Kat (2003) for a graphical representation of a large number of studies showing this pattern; but for a contrasting view, see Tassinari, et al., 1994 and Danzinger & Kingstone, 1999). It has been shown that IOR can be observed not only with manual responses (e.g. Maylor & Hockey, 1985; Posner & Cohen, 1984) but also with eye movements (e.g. Abrams & Dobkin, 1994; Vaughan, 1984); not only in detection tasks (e.g., Tassinari et al., 1994) but also in discrimination tasks (e.g. Lupianez et al., 1997; Pratt & Castel, 2001); not only associated with environmental loci, but also with objects (e.g., McCrae & Abrams, 2001; Tipper, Jordan, & Weaver, 1999; Tipper et al, 1994).

Posner and Cohen suggested that IOR may have evolved as a mechanism that encourages orienting towards novel locations. Since this effect has been found in work with people across the life span, for example, 6- to 18- month-old babies(Clohessy, Posner, Rothbart, & Vecera, 1991), elderly and younger adults (Hartly & Kieley, 1995; Faust & Balota, 1997), now researchers assume IOR is an automatic effect that is intrinsic to the visual attention system(Clohessy et al. 1991; Butcher et al, 1999).

Note that the effect of inhibition described here does not necessarily mean that selection only can be performed by inhibition and suppression of irrelevant information; selection can definitely be accomplished by excitation and enhancement of behaviorally relevant information too. Both mechanisms may operate in concert, though this still remains in debate (Milliken & Tipper, 1998).

The cause of IOR

Obviously, the name "inhibition of return" itself implies both a cause and an effect: the cause of IOR was attributed to orienting of attention towards a location and the subsequent removal of attention from the location (e.g. Law et al. 1995; Klein, 2000).

According to Posner and Cohen (1984), IOR follows the facilitation associated with attentional capture by an event in the periphery but it does not follow a voluntary shift of attention in the absence of peripheral stimulation (also see Rafal et al., 1989). To observe IOR in a cue-target paradigm, two conditions must be satisfied: the cue must have caused IOR and the task performed must be sensitive to IOR's effects (Klein, 2000; Taylor & Klein, 1998). The importance of these constraints can be seen in the fact that when attention is endogenously cued (without an event in the periphery to guide it), the attention withdrawal from the cued location does not result in IOR effect (Posner & Cohen, 1984; Rafal, Calabresi, Brennan, & Sciolto, 1989). As noted by Taylor and Klein (1998), having an early facilitation replaced by a later inhibition depends on the withdrawal of attention back to fixation following initial exogenous capture by the peripheral cue (Maylor & Hockey, 1985; Possamai, 1986; however, see Rafal & Henik, 1994). Thus, to cause the IOR, (1) the observer must first direct attention to that location, and (2) attention must then be removed from that particular location of the cued stimulus.

As noted above, it is also important to factor in any facilitatory effects that might be present. In Posner and Cohen (1984), facilitation of return (FOR) was obtained only when target occurred overlapped with or else near to the cue presentation in temporal proximity. In fact, they found a biphasic pattern with cues provided by a 150 ms brightening of a peripheral box in which the target occurred at 0, 50, 100, 200, 300, or 500 ms after the onset of the cue. Facilitation was observed for first three intervals and was followed by IOR at the longer intervals. However, the results were not supported by several different studies. For example, Possamai (1986) studied the relationship between late inhibition and early facilitation. In his experiment, the cue and the target randomly appeared in one of the three locations (fixation, left/right of fixation) (p=1/3). If the targets appeared in the peripheral locations, typical facilitation and inhibition pattern of results was appeared, however, cued central targets were always responded to slower than uncued ones. It seems that inhibition is not dependent on the emergence of the facilitation. Notably, these findings did not fit well with two ideas of Posner and Cohen (1984): inhibition is a consequence of the movement of attention away from the cued location; there is a close relationship between the inhibitory component and the movements of the eyes[3]. Another important research was done by Tassinari, et al. (1994). In their experiments, participants were required to respond to a target displayed for 16 ms following at stimulus onset asynchronies (SOAs) of 0, 60, 130, 300 or 900 ms. The duration of the cue varied between experiments: (1) cue was presented 16 ms; (2) cue offset always occurred 300 ms after the target onset, (3) cue duration was 130 ms. Their results showed that there was no RT facilitation with targets in cued locations at any SOAs. Another important finding from these experiments is that no inhibitory effect appeared for targets in cued locations if the cue remained on during target presentation and outlasted target offset. They concluded that "facilitation of RT to targets in cued positions, if any, does not precede and cause inhibition, but co-occurs with it" (p179).

Several studies on the cause of IOR have found evidence in favor of oculomotor activation. Rafal et al. (1989) studied how the neural systems responsible for the covert allocation of visual attention are integrated with the oculomotor system. To signal the subjects to execute an eye movement, or to just prepare an eye

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[3] "Once the eyes move away from the target location, events that occur at that environmental location are inhibited with respect to other positions" (Posner and Cohen, 1984, p550).

movement (saccade), or to shift visual attention without shifting gaze, the authors presented arrows at fixation or presented a luminance change in the periphery (see Table 1). The results showed that significant inhibition appeared if the target was presented at locations that subjects had planned to fixate or actually had just fixed, regardless of whether the cue to do so had been in the central or peripheral. In the "attend" condition, the inhibitory effect was observed if the cues were exogenous ones (i.e., peripheral). However, no inhibitory effect was observed if the cue was endogenous ones (central endogenous cue) in the "attend" condition, which is consistent with Posner and Cohen (1984). Rafal et al's results suggested that the IOR is elicited by activation of oculomotor programming.

Conditions tested by Rafal et al. (1989)		
	Cue types	
Response to cues	Exogenous	Endogenous
Execute saccade	Yes	Yes
Prepare saccade	Yes	Yes
Attend	Yes	No

Table 1. Summary of Rafal et al. (1989) (also see Klein, 2000, p139). "Yes" indicates the inhibitory effect was significant at the cued location.

Another typical study was reported by Klein, Christie & Morris (2005). In their study, one to four uninformative cues were displayed simultaneously in randomly selected locations on a virtual circle around fixation (200ms), followed by a central cue (200ms). The target appeared immediately after the central cue (SOA: 400 ms) or 1,100 ms later (SOA: 1,500 ms) at one of the eight peripheral locations. Unlike previous studies, the authors examined performance as a function of the angular distance between the target and the average direction of the cue(s). For multicue arrangements, the substantial average vectors were combined. The authors observed IOR in the net direction of a cue whether or not the target fell on a stimulated location. However, when the cues' elements were balanced around fixation (such that the net vector of the cue was zero) no IOR was observed.

As mentioned above, covert orienting can be accomplished by the operation of two distinct but interacting control systems: endogenous and exogenous (Klein & Hansen, 1990; Klein, Kingstone, & Pontefract, 1992; Theeuwes, 1991). Because peripheral stimulation automatically activates the oculomotor system while a voluntary shift of attention in the absence of eye movements does not (Klein, 1980; Klein & Pontefract, 1994), the results indicates IOR is generated by peripheral stimulation, oculomotor activation, or both.

The effect of IOR

What is inhibited as a result of prior cue presentation? According to Ponser et al. (1985), the effect of IOR was to discourage attention from re-orienting back to the originally attended location. Obviously, the terminology, "Inhibition of Return", derives from the belief that attention is drawn reflexively to the location of the luminance cue and that, following the withdrawal of attention back to fixation, attention is prohibited for returning to the previously cued location. This is a popular interpretation of the IOR effect. The indexes used usually look for a reduction in the speed and/or efficiency of perceptual processing at that location.

Although Posner and his colleagues (1984) concluded that the cued location in visual space is facilitated early and inhibited later, their account of space-based attention may be confounded with the possibility that their participants probably viewed the boxes as objects, rather than or in addition to, viewing them as locations. When a cue appears at such a box, both the cued object and the cued location will become inhibited (Leek, Reppa & Tipper, 2003; Jordan & Tipper, 1998; Tipper, Driver & Weaver, 1991; Tipper et al. 1994). In examining the possible role of IOR in search behavior, Tipper et al. (1991) proposed that IOR would be useful if inhibition of return happens no only in static objects but also in dynamic objects. Further studies indicated that IOR has both an object-based component (that moves with the cued object) and a location-based component (that remains at the cued location); the two components can also exist simultaneously (Tipper et al., 1994). IOR found in a static display is a combination of both the object-based and location-based components of IOR, hence is larger than that found when the cued object is moved to a new location prior to the target appearance. Some researchers have reported more IOR for cued objects than for cued locations (e.g. Jordan & Tipper, 1998; McAuliffe et al., 2001; McAauliffe, Chasteen & Pratt, 2006); but others have reported stronger location-based IOR than object-based IOR (e.g. McCrae & Abrams, 2001).

Some findings indicate that IOR maybe more closely associated with responding than with perceptual processing. For example, Klein and Taylor (1994) supported an <u>oculomotor activation</u> hypothesis, rejecting the <u>inhibited attention</u> view. They noted that attention affects discrimination (like form, color or size) and that IOR had been observed with simple detection, manual localization and saccadic responses, but had not been obtained when the task involved a non-spatial discrimination task (Terry, Valdes & Neill, 1994). Based on this dissociation, they speculated that attention was not inhibited by IOR. Instead, they proposed a motor view: IOR is a reluctance to respond to an event at the inhibited location, that is, IOR is more closely associated with responding than with attention. There is good evidence for this position. For example, as we have described above, Rafal et al. (1989) presented arrows at fixation or luminance changes in the periphery to signal the subject to execute or prepare an eye movement (saccade) or to shift visual attention without shifting gaze. They found when the cues were used to direct attention and the subjects were required to keep their eyes fixed, IOR was observed following peripheral cues (these cues initiated the oculomotor system). We know that in Posner and Cohen's original experiments, IOR did not appear following central cues (in this situation, attention was generated independently of oculomotor programming). More important, when oculomotor preparation occurred (without actual execution of the movement), IOR appeared at the to-be –fixated location. In this case, there was no peripheral stimulus so this result strongly supports the motor bias view. Further evidence was obtained by Klein, Christie & Morris (2005). They observed that IOR appeared in the net direction of a cue regardless of whether the target fell on a stimulated location or not. Moreover, when the cues' elements were balanced around fixation, there was no IOR.

As we have mentioned above, a biggest reason for Klein and Taylor (1994) to reject the "inhibited attention" view is that "IOR had not been observed with non-spatial discrimination tasks" (Terry, et al, 1994) but attention affects such discriminations. However, subsequently numerous investigators did find IOR with non-spatial discrimination tasks (e.g. Cheal, Chastain & Lyon, 1998; Lupianez, et al., 1997; Pratt, Kingstone, & Khoe, 1997). This leads to a speculation that difficulty of the target discrimination affects the timing of IOR and the benefits, together with the response-repetition strategy obscures IOR. In particular, Reuter-Lorenz et al. (1996) reported that the magnitude of IOR and attentional facilitation were similarly affected by changes in target intensity and modality. Obviously, this result provides another evidence for the "inhibited attention" view.

The debate over whether IOR occurs at a perceptual level of processing or instead is just a bias against responding to stimuli from the cued location has been contentious. On one hand, converging evidence for the original proposal (Posner et al.1984, IOR reduces perceptual sensitivity) comes from several behavioral studies (e.g. Cheal & Chastain, 1999; Handy et al., 1999; Ivanoff & Klein,2006) and from imaging studies (e.g. McDonald et al., 1999) showing early components of the brain's electrical response to a target. On the other hand, researchers have also provided solid evidence demonstrating that IOR biases performance against responding to stimuli from the cued location (e.g. Ivanoff & Klein, 2001, 2004, 2006; Ivanoff & Taylor, 2006).

A more acceptable conclusion is that both of these effects may contribute to the role of IOR as a search facilitator. Considering these results, Klein (2004) proposed that a more fruitful strategy might be to determine the boundary conditions for eliciting effects. For example, if the task is a go/no-go simple detection task (e.g. Ivanoff & Klein, 2001; Klein & Taylor, 1994), the dominant factor may be an inhibited response to the cued targets. In contrast, if the task is more related to a nonspatial discrimination, input processing (attention) seems to be affected directly or through an IOR-mediated delay of orienting to the target (e.g. Klein & Dick, 2002).

Currently, some researchers also employ the imaging techniques to explore the effects of IOR. Some studies consistently observe negative effects of IOR on the P1 ERP component (e.g. Eimer, 1994a,b; Hopfinger & Mangun, 2001; McDonald et al., 1999; Wascher & Tipper, 2004) and this component is thought to reflect sensory processes. Prime and Ward (2004, 2006) reported that IOR was not only associated with the amplitude reduction of visual P1 component, but also with the amplitude reduction of visual N1 component. Both P1 and N1 dipoles were located in the extrastriate cortices (Di Russo et al. 2001). In contrast, the motoric ERP components (LRP: lateralized readiness potential) did not seem to be affected by IOR directly (Prime & Ward, 2004, 2006). Thus the evidence available from ERP research supports IOR's perceptual/attentional basis.

Because ERP offers high temporal resolution but poor spatial resolution, researchers have used functional magnetic resonance imaging (fMRI) to isolate the location of the effects of IOR. Some fMRI studies support the view that IOR is not related to the early processing in the extrastriate cortex, but is related to the oculomotor system in frontal lobe (e.g. Lepsien & Pollmann, 2002; Mayer et al., 2004a, b). For example, Lepsien and Pollmann reported that IOR was accompanied by increased activation in primary oculomotor areas, including the right medial frontal gyrus (supplementary eye filed;SEF) and the right inferior precentral sulcus (frontal eye field; FEF). This result is consistent with the oculomotor bias theory of IOR. More recently, using a special symbolic cuing pattern [1], Muller and Kleinschmidt (2007) reported the blood oxygenation level dependent (BOLD) responses to targets presented shortly after the cue were more pronounced in "valid" than in "invalid" trials. And, at the long SOA, targets showed at invalid locations produced larger BOLD response. Specifically, the long SOA condition yield stronger activation in areas like frontal eye field (FEF), (pre)supplementary motor area (SMA), superior colliculi (SC) and posterior parietal cortex (PPC) and these areas are thought to belong to the oculomotor control system.

So up to now, the available data from imaging studies seem to allow no firm conclusions for the oculomotor activation hypothesis or attention inhibition view. It seems that the neural substrate of visual orienting is guided by immediately preceding sensory experience, and then the fast-reacting brain system modulates the sensory processing.

[1] Considering that peripheral cue is processed in the same retinotopic visual cortical regions as the subsequent target, the authors thought it impossible to disentangle attentional modulation of target processing from sensory cue-target interactions, hence they employed symbolic cues over peripheral ones.

Given the visual input changes from moment to moment, perceivers need to select relevant information from time to time. If IOR were to play a role in search, it should be initiated rapidly enough, that is, it should be expressed once a distractor has been inspected and rejected, and it should last long enough to be useful in the search episode. Meanwhile, it is reasonable to assume it should be able to tag multiple locations. Then how quickly does IOR develop? What is its the spatial distribution? Given the number of dimensions used in the IOR literature have differed from each other, it is not surprising that traditional narrative reviews of this literature have found it difficult to arrive at definitive conclusions on the temporal and spatial characteristics of IOR.

Time Course How quickly does IOR begin and how long can it last? To clearly address these questions, we must examine how quickly IOR develops and when it begins to dissipate.

In their simple luminance detection task, Posner and Cohen (1984) varied the interval between the onset of the cue and the onset of the target and demonstrated IOR begins at a cue-target SOA of 225 ms (see Figure 4). Early facilitation has been explained by an automatic covert orienting towards the cue, while the following inhibition is a consequence of such covert orienting. A line of studies demonstrated that IOR at long SOAs followed facilitation at short SOAs, hence it belongs to a biphasic effect (e.g. Posner, Rafal et al., 1985; Rafal & Henik, 1994). Two different construals of the timing of IOR have been proposed. Some researchers held this view:

the biphasic pattern reflects a facilitation that lasts until attention is removed from the originally cued location, and the inhibition begins with this removal. Others propose that inhibition begins with the cue, and hence takes place in parallel with facilitation. This view assumes the initial facilitatory effect on RT is larger than the inhibitory effect, but later lesser than the inhibitory effect (Klein, 2000, Box 1). There is also evidence that IOR exists at both short and long SOAs (Berlucchi, et al., 1989; Tassinari, Aglioti et al., 1994; Tassinari & Berlucchi, 1996; Tassinari, Biscaldi et al., 1989).

A first extensive review of the temporal property of IOR was done by Collie et al. (2000). In their review, only detection task data were included, and studies were required to have reaction time (RT) as their dependent variable. Significant IOR was found between 130 ms and 1,500 ms. Klein (2000) reviewed studies using a cue-target task with saccadic localization response as the dependent variable (see Figure 6, top panel). It indicates that IOR begins more quickly when saccadic responses are made than when manual responses are required (e.g. Briand et al., 1998).

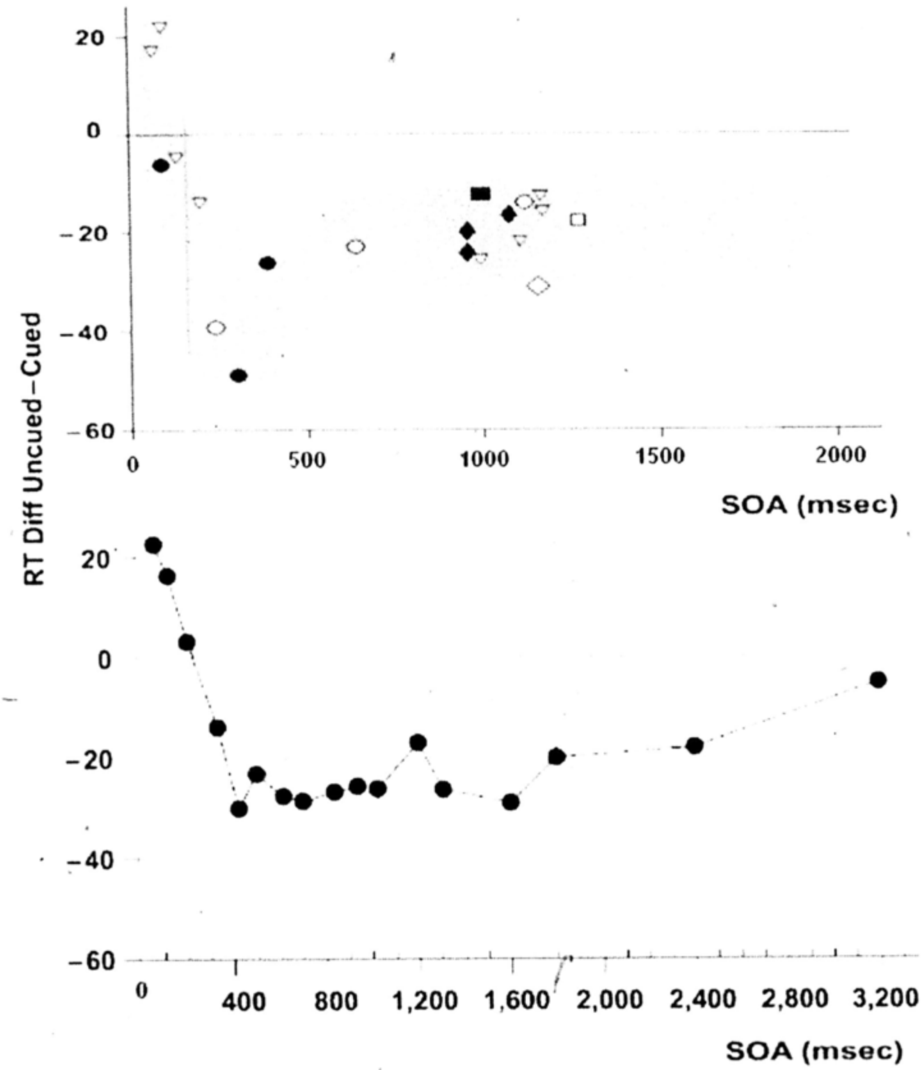

*Figure 6.*Top panel: "cue-saccadic" data of 6 studies reviewed by Klein (2000); Bottom panel: "cue-manual" average scores of 27 studies reviewed by Samuel and Kat (2003).The subfigures were adapted from the original papers.

A more recent review was done by Samuel and Kat (2003). They used at least a hundred data points for their meta-analysis. The criteria for their data selection were that the experimental conditions involved target detection following a cue, with a timed manual response. To date, this graphical meta-analysis presents the clearest data as to when IOR begins and when it ends (see Figures 6). Based on the results described above, it seems that for cue-manual pattern, the IOR effect develops at about 200 ms and diminishes at about 3,000 ms following a cue.

Actually, there exists some debate on this issue. Researchers first claimed that visual search is "memory-free", which would imply that no record would be kept of how the perceiver deployed attention during a search (Horowitz & Wolfe, 1998). It is assumed that in a dynamic natural world, the contents of the scene usually change rapidly; IOR would not be helpful (advantage) if "a predator was initially and irrevocably misidentified as a rock" (Horowitz & Wolfe, 2001, p273). Wolfe, Alvarez & Horowitz (2000) demonstrated that objects/locations may be searched as quickly as one item every 13-44 ms. Given such rapid search, if IOR is to help, it would need to develop extremely rapidly. In addition, if IOR influences search efficiency, it would be more helpful if the effect can last long enough, especially in a long and complex searching task.

Horotitz and Wolfe (2001) indicated that inhibition of return (IOR) should not be observed in tasks if they involve rapid deployment of attention. This was the basis for their conclusion is that IOR does not exist when attention is shifted rapidly between locations. However, Dodd et al. (2003) sequentially cued six possible locations with either a short-duration time (50 ms) or long-duration time (500ms) and observed IOR at every cued location with the long-duration cues. But IOR was found at only one cued location for the short –during cues (the second to last). They did observe IOR with almost all locations at both the short- and long-cue condition when the final fixation cue was removed. Dodd et al.'s results demonstrate that IOR can be observed at multiple locations when attention is shifted rapidly between cued locations.

Dodd and Pratt (2007) further examined whether the IOR can be observed outside the normally reported temporal boundaries (300 – 3000 ms) when attention is shifted very quickly (15 ms) or very slowly (1,500 ms). The authors used a modified version of the multiple cuing paradigm used by Dodd et al. (2003). IOR was observed as quickly as 30 ms following the cue onset and as long as 6,000 ms following the cue onset.

Spatial Distribution Researchers have also studied the spatial distribution of inhibition of return. Several investigators (e.g., Bennett & Pratt, 2001; Maylor & Hockey, 1985; Samuel & Weiner, 2001) have shown that the inhibitory effect is strongest at the location of the cue, and falls off with distance from that location.

Maylor and Hockey (1985) used a display consisting of two sets of seven vertically aligned placeholders (Exp2: situated to the left and right of the fixation). In their procedure, the cue occurred in the middle placeholders, followed by a target which could occur in any of eight placeholder locations (seven locations on the cued side, plus the uncued middle location) after a certain SOA. The results showed that IOR was not limited to the cued location, but was progressively weaker the further the target was from the cued location. Marzi and Di Stefano (1989) have suggested that the IOR spreads symmetrically from the cued location until stopped by either the vertical or the horizontal meridian, which is an important possible constraint on the spatial distribution of IOR. Similar results were also reported by Tassinari et al. (1987) and Tassinari and Campara (1996).

A more extensive study was done by Bennett and Pratt (2001). These authors used a typical IOR procedure (cue, delay, target) with four locations and 441 target locations (each separated by 1^0 of visual angle), probing the spatial distribution of IOR with high spatial resolution. Their results produced a gradient of RTs throughout the visual field, with inhibition in the cued hemifield gradually giving way to facilitation in the hemifield opposite the cue.

Nonspatial-based inhibition of return

Whether IOR is a general phenomenon still remains in dispute. Some evidence supports the idea that IOR plays a strong and important role in visual search (e.g. Klein, 1988; Klein & MacInnes, 1999), while other evidence suggests a limited role or no role for IOR in visual search (e.g. Gilchrist & Harvey, 2000; Horowitz & Wolfe, 1998; 2001; 2003).

The observation of object-based IOR raises some very basic questions about the nature of inhibitory processes in visual search. As long as the effects were limited to location-based cases, models of the process could naturally assume that the inhibition was spatially determined. If search can be directed toward (or away from) particular objects that can occur at any location (or even changing locations), specifying the target for facilitation or inhibition can no longer be done in the default parameter space of the visual system. This opens up the possibility that inhibition can be associated with nonspatial attributes, such as color, shape and orientation, since objects may be defined by a configuration of such features. More generally, this raises the question of whether a scene can be thought of as a set of objects that each have a number of associated properties, one of which is location; from this perspective, spatial properties are not inherently different than other properties of the object.

However, most theorists do see a special role for location, relative to other properties. For example, in classic models of search (e.g., Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989), objects are specified by collections of features that co-occur in internal "maps" that are spatially organized. Thus, a fundamental issue is whether location is qualitatively different than other features (see Tsal and Lavie, 1988, 1993).

If location is fundamentally different than other properties that an object may have, then it may enjoy a privileged status with respect to facilitation and inhibition. In fact, the vast majority of research examining inhibition of return has focused on the inhibition of processing to a previously cued location. Those studies on IOR led researchers to attribute IOR to a general cognitive mechanism. If that is the case, it is then reasonable to expect similar IOR effects with feature stimuli, such as color, shape, orientation, etc. However, only a few studies have examined feature-based IOR (with color: Busse, Katzner & Treue, 2006; Kwak & Egeth, 1992; Law et al.1995; Tanaka & Shimojo, 1996; Lupianez et al, 1997; with shape: Morgan & Tipper, 2007; Morgan, Paul & Tipper, 2005; Lupianez et al, 1999; Pratt et al, 1997; Pratt, 1995; with orientation: Busse, Katzner & Treue, 2006; Kwak & Egeth, 1992).

Briefly, there is evidence both for and against feature-based IOR. In a series of experiments, Kwak and Egeth (1992) only observed location-based IOR, and failed to find color- or orientation-based IOR. Similar results were reported by Tanaka and Shimojo (1996). They supposed that there exists a functional dissociation between spatial orienting and feature analysis, as well as a top-down modulation by tasks leading to different types of visual processing.

In this small literature, Kwak and Egeth (1992) were the first to look for color-based IOR. They reported a set of experiments using a target-target procedure. In this paradigm, subjects do a series of trials, and the stimulus (target) presented on trial N serves as the cue for the stimulus (target) presented on trial N+1. Across experiments, Kwak and Egeth varied the number of locations at which colored squares could appear, with response-to-stimulus intervals varying from 400 ms to 1,400 ms. The participants were required to hit a response key whenever they detected a stimulus, at any of the possible locations. The stimuli were small colored squares, and the question was whether responses would be slower on trial N+1 when the color was the same on trial N than when it had been a different color. Although strong location-based IOR was observed in all experiments (responses were slower on trial N+1 when the stimulus on trial N was in the same location), in most of the experiments no color-based IOR was found. The authors found a significant color-based IOR effect in only one experiment: When there were four possible locations, there was 5-ms color-based inhibitory effect, but only when the stimuli on trials N and N+1 shared both color and location. Based on the preponderance of their evidence, Kwak and Egeth concluded that there is no inhibition based on color. Using the target-target procedure, with a number of different tasks, Tanaka and Shimojo (1996) also concluded that inhibitory effects are generated by location, but not by color (but see Pratt & Castel, 2001).

The negative results led some to suggest that the target-target procedure is not an appropriate test for attribute-based IOR. In an influential paper, Law, Pratt, and Abrams (1995) argued that to elicit color-based IOR, attention must first be directed toward to the attribute, and then attention must be removed from it. This is, after all, the basic premise for the notion of inhibition of return – attention must be removed in order to have the opportunity to inhibit its return. In the target-target procedure, consecutive trials of, say, red targets would have no obvious point at which attention was removed from "red" after the first target. In Law et al.'s study, all stimuli were displayed at fixation, using a cue-target procedure more like that of Posner and Cohen (1984); the cue did not require a response, whereas the target presented 900 msec later did. Their critical procedural change was to present a neutral "attractor" square between the cue and target. The attractor was irrelevant to the task (detecting the target square), and was colored differently than the cue and target squares. In two experiments that included a neutral attractor, they obtained significantly slower detection times (about a 6 msec effect) when the cue and target shared the same color than when they were colored differently; when no attractor was included, no difference was found. They concluded that the lack of a neutral attentional attractor led to the failure to observe color-based IOR in previous research (e.g., Kwak and Egeth, 1992).

Taylor and Klein (1998) replicated Law et al.'s (1995) procedures and results, but did so in a context that led them to question whether the effect is actually a version of inhibition of return. In addition to the 900 msec SOA that Law et al. had used, Taylor and Klein tested SOAs of 150, 300, 450, 600, and 750 msec, in each case either with or without an intervening attractor between cue and target. Recall that a defining property of "classic" IOR is its time course, with an onset at approximately 300 msec (Samuel & Kat, 2003). From this perspective, there should have been no inhibitory effect for the 150 msec SOA condition, and a small or non-existent one at 300 as well; in fact, there should have been a facilitation effect at the shortest SOAs. Instead, Taylor and Klein observed an essentially constant inhibitory effect of about 14 msec for the conditions with the attractor, regardless of SOA, and no effects for the conditions without the attractor. Given this mismatch with a fundamental property of IOR, the authors suggested that their effect, and that of Law et al., was more likely due to some other mechanism, perhaps repetition blindness (Kanwisher, 1987, 1991). In repetition blindness studies, subjects often miss the occurrence of a second presentation of a stimulus, when the second presentation follows soon after the first one; the typical timecourse for repetition blindness is a few hundred milliseconds, a better match to the timing of Taylor and Klein's effects. Thus, Taylor and Klein concluded that "the results that Law et al. reported are interesting, but do not demonstrate IOR for color" (p. 1455).

In an extensive set of experiments, Fox and de Fockert (2001) examined the effects of the attractor, the location of critical stimuli (at fixation versus more peripheral), and the timing between the cue and target. In addition, they conducted parallel experiments using color and shape as the critical attributes. They convincingly replicated and extended Law et al's findings, showing that for stimuli presented at fixation, a consistent inhibitory effect occurs both for color and shape repetition when a neutral attractor intervenes, but that no inhibition is found without the attractor. Similarly, the color- or shape-based inhibitory effect disappeared if the stimuli were presented in peripheral locations rather than at fixation. With SOAs comparable to those of Law et al., the effects were in the 8-12 msec range, but the magnitude of the effect tended to decline as the SOA was increased from 200 to 900 msec. In accord with Taylor and Klein (1998), the authors noted that true IOR effects tend to increase over this range of SOA, rather than decrease. More generally, they suggested that the pattern of results was more similar to those in the repetition blindness literature than to those in the inhibition of return literature.

Riggio, Patteri, and Umilta (2004), focusing on the shape attribute rather than color, followed up Fox and de Fockert's (2001) study with a set of experiments that tested both the role of the attractor, and the possibility that the effects were in the repetition blindness family, rather than true inhibition of return. Their experiments tested whether detecting a recently seen shape is slower than detecting one that has not just been presented. In three experiments that did not use a neutral attractor they found shape repetition costs of about 5 msec at fixation, and about 10 msec at two peripheral locations. As in Kwak and Egeth's (1992) study, these significant peripheral effects only were found when the cue and target shared location. To tease apart repetition blindness from IOR, Riggio et al. took advantage of the fact that repetition blindness can be found when two items share the same phonological identity (e.g., "bear" and "bare"), even if they do not share physical identity. Thus, cue-target pairs like a-A, or b-B should produce repetition blindness, but not shape-based IOR. Riggio et al. found that physically-identical shapes (e.g., a-a) produced the repetition cost (when they shared location), but that the physically different pairs (e.g., A-a) did not, a result that is at odds with repetition blindness being the source of these effects.

Collectively, the results from studies of nonspatial-based inhibition of return are rather murky: It is clear that under some circumstances it is more difficult to process a stimulus if it shares its special nonspatial attribute (feature) with a recently viewed stimulus, but the temporal and spatial properties of this effect do not match those for the well-studied location-based inhibition of return. For color and shape attributes, the most robust attribute-based effects have been found at fixation, with a neutral attractor between the cue and target, at SOAs that are shorter than those typically found for IOR. Most of the reaction time differences for color-based effects have been in the 5-10 msec range, whereas the typical IOR effect in the literature is about 25 msec (Samuel & Kat, 2003); in many of the studies finding these small color-based effects there were also location-based IOR effects that were of the typical size. The pattern of effects, along with its differences from the typical IOR pattern, has led some authors to suggest that the nonspatial attribute-based effect is more likely to be some kind of repetition blindness, rather than inhibition of return.

There are some hints in the existing color-based literature that inhibitory effects may only become apparent when the test displays provide a certain level of processing complexity. For example, the introduction of a neutral attractor potentially requires the system to process a series of rather rapid changes, from the representation of the cue, to that for the attractor, to that for the target. In addition, the only condition in Kwak and Egeth's (1992) original study that produced a significant inhibitory effect was one that presented stimuli at four different possible locations; no effects were found in experiments using only one or two locations (and all of the other studies in this literature were limited to one or two locations).

The present thesis: Toward a complete assessment

As the literature review illustrated, we really do not have convincing evidence to determine whether non-spatial attribute-based IOR occurs—there are mixed results regarding the existence of the attribute-based IOR. In the present thesis, we will report results that we believe offer a clearer answer than is currently available.

The present study aims to thoroughly examine a possible nonspatial attribute-based (including color, shape and orientation) inhibitory effect. The first issue is "whether": does such an effect exist? If so, then the next issue is "when": under what conditions does the nonspatial attribute-based IOR occurs during vision search? The answers to these two questions are potentially very important in providing a theoretical account of the mechanisms of inhibition.

As indicated previously, under suitable conditions to demonstrate IOR, it seems reasonable to propose that IOR can emerge rapidly and coexist at multiple locations if IOR has a real impact on visual search. Most previous examinations of time course relied on the Posner and Cohen (1984) paradigm for measuring IOR. Unfortunately, however, among these studies, the majority of IOR experiments involved very simple displays, usually with a relatively easy task (e.g. simple detection). The handful of studies that have found attribute-based repetition costs suggest that these unusually simple conditions are not well suited to test non-spatial attributes in visual search. In contrast, Samuel and Weiner (2001) reported a series of location-based IOR experiments that used displays that were more complex than those typically used in IOR experiments. The paradigm was designed to allow many possible manipulations, while still keeping very tight experimental control. Samuel and Kat (2003) adopted this methodology to examine the spatial and temporal properties of IOR, and given the relatively complex displays, it may also be well-suited to look for color-based IOR effects.

General experimental approach

In a typical experiment of Samuel and Weiner (2001), the display had eight medium-sized gray circles arranged in an imaginary circle around fixation. In each of the gray circles, there were 0, 1 or 2 smaller figures. In the two published studies using this paradigm, four types of small figures were used: red disks, blue disks, red boxes, and blue boxes; of course, these choices can be adapted to the needs of the particular question being studied. A typical trial sequence, consisting of four sequential frames, is illustrated in Figure 7.

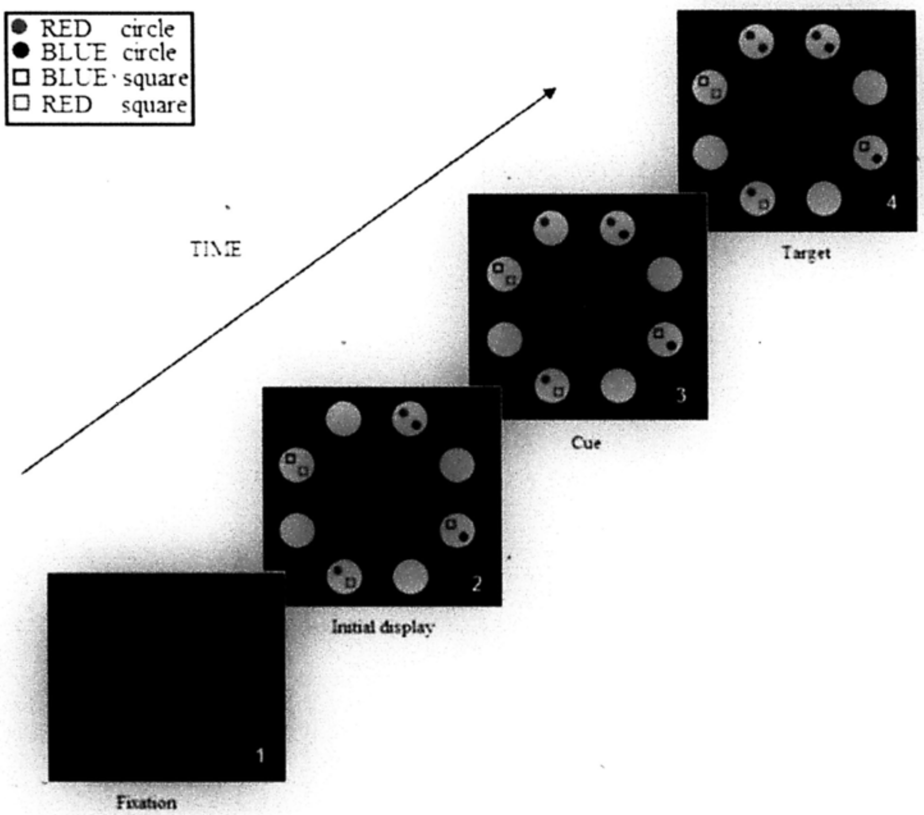

Figure 7. The sequence of events for a sample trial in Samuel and Weiner (2001). But note that in the actual displays, each frame was a 480 x 640 pixel display.

First, a frame with a white fixation cross (1^0) appears on a dark gray background for 250 msec. The second frame (750 msec) includes eight light gray circles (diameter = 3.7^0), arrayed in a circular fashion around the fixation cross (radius=6.8^0). Four empty circles alternate with four filled circles, each of which contain two small (1^0) figures. In Frame 3, as a cue event, a new small figure appears (red or blue, disk or box) in one of the four empty circles. The cue-target SOA is manipulated by varying the duration of Frame 3. Finally, in Frame 4, as the target event, another colored box or disk is presented. The target occurs equally often within the same gray circle as the cue ("Same" condition), 90^0 away ("Diff1" condition), or 180^0 away ("Diff2" condition). As shown in the example figure, on a "Same" trial, the cue and the target events occur within the same gray circle, but always in slightly different positions. IOR is defined as target detection that is slower in the "Same" condition than in the "Diff" conditions. Samuel and Weiner (2001) found robust IOR effects using this paradigm, with reaction time costs for the Same case about twice as large as those found with the more typical two-location task of Posner and Cohen's (1984) type. Samuel and Kat (2003) found that the task also provided good spatial resolution for the IOR effect, seen in differences between the Diff1 and Diff2 locations (see Paradigm validity assessment experiment below).

However, before taking on these primary issues, we felt it was important to first replicate the basic paradigm, since all of the published results from this task have come from a single laboratory. Thus, a preliminary experiment below implements this paradigm in a different laboratory using different hardware, different software, and a different subject population (subjects in China, versus those in the US).

Chapter 2: Paradigm and validity assessment

The primary goal of this chapter is to test Samuel and Weiner's (2001) paradigm in a different laboratory, to provide an empirical context for its use to test nonspatial-based IOR. A second goal was to look at the time course of location-based IOR, integrating the relatively short SOAs (maximum SOA of 610 msec) tested by Samuel & Weiner (2001) with the relatively long SOAs (600 – 3200 msec) tested by Samuel & Kat (2003). As in those studies, the task is designed to clarify both the temporal and spatial properties of IOR.

Paradigm Assessment

Method

Participants Twenty undergraduate and graduate students from Peking University were recruited. Ages ranged from 17 to 33 years (Mean = 24 years). All reported normal or corrected-to-normal acuity and color vision, and all were naïve to the purpose of the experiment. Participants were tested individually, and each was paid 25 RMB per hour.

Apparatus and Procedure The apparatus, stimuli, and procedures were modeled on those of Samuel and Weiner (2001) and Samuel and Kat (2003).

The experiment was run in a dimly illuminated room. Participants sat at a viewing distance of approximately 63 cm with their heads supported by a chinrest. Stimulus presentation and data collection were conducted on a Pentium IV computer running E-Prime software (Schneider et al., 2002). The monitor was refreshed at an 80 Hz rate. A computer keyboard was directly in front of the subject and its space bar was used as the response device.

Each trial followed the sequence of events described above, and illustrated in Figure 6. SOAs of 200, 350, 700, 1500, 2500, and 3500 msec were chosen to span the full range of IOR that has been found in previous research. 96 target-present cases (4 locations of first onset x 4 possible target locations x 6 SOAs) were presented in each block of the experiment. In addition, 16 catch trials were included, in which a cue but no target appeared; subjects were instructed to withhold responses on trials with no targets. Thus, there were 112 randomly ordered trials per block. Each trial ended either after the participant had responded, or 3,000 msec after the target onset. The inter-trial interval was 1,000 msec. The experiment consisted of four blocks (a total of 448 trials), with a short rest period offered after each block.

Each participant first performed a practice block of 30 trials that were not analyzed. Both speed and accuracy were stressed. If a subject responded on a catch trial, or responded in less than 100 msec after the target onset (an anticipatory response), a brief alarm tone was presented. Similarly, if a reaction time exceeded 3000 msec, the tone was played.

Results and Discussion

The aim of the Preliminary Experiment was designed to determine if the current experimental setup is an appropriate instantiation of the paradigm used by

Samuel and colleagues (Samuel & Weiner, 2001; Samuel & Kat, 2003), in preparation for the test of attribute-based IOR using this paradigm.

An initial analysis was conducted on response accuracy. Two participants' data were excluded from further analysis because of high error rates (more than 5%). In addition, one participant's data were excluded as a result of very slow response times (most RTs>700 ms). For the remaining 17 subjects, the miss and error rates were very low, averaging less than 1%. Figure 8 presents the mean target detection times, broken down by the location of the target. Overall, targets were responded to relatively quickly, with a mean reaction time of 388 msec.

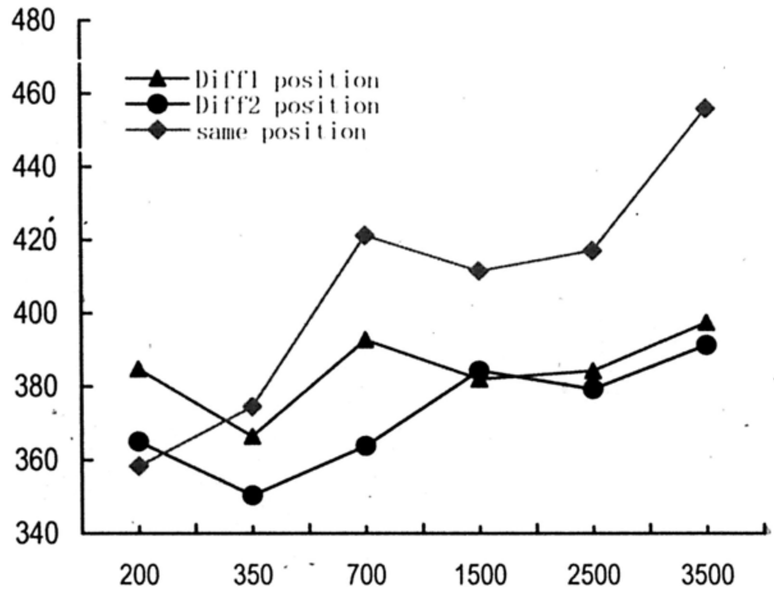

Figure 8. Time course of IOR with manual response.

The original work with Samuel's paradigm produced two central results: (1) large IOR effects that increased when the SOA was increased beyond 200-300 msec, with a trend toward smaller IOR as the SOA approached three seconds; and (2) a spatial gradient to the IOR effect for approximately one second. The first effect was measured by slower detection times for targets in the Same location versus those in either of the Diff1/Diff2 locations (see Figure 9a), while the second was indexed by any differences for targets in Diff1 versus Diff2 locations (see Figure 9b).

We conducted a two-way analysis of variance on the reaction times to see whether the Preliminary Experiment yielded results comparable to those in the previous work with this paradigm. One factor was Location (Same, Diff1, and Diff2), and the second was SOA (200, 350, 700, 1500, 2500 and 3500 msec). Both of the major effects we are interested in would be manifest in an interaction of Location and SOA, and this interaction was in fact significant, $F(10, 160)=6.69$, $p<.01$. In addition to the interaction effect, both main effects were significant: Location, $F(2,32)=32.89$, $p<.01$; and SOA, $F(5, 80)=12.52$, $p<.01$.

Samuel and Weiner (2001) found a significant facilitation effect for their SOAs under 300 msec, and in the current study there was a similar pattern at the 200 msec SOA, with targets detected fastest at the Same location. This advantage did not reach significance compared to targets at Diff2 [$F(1,16) = .34$, $p>.57$], but was significant versus Diff1 [$F(1,16) = 12.39$, $p<.01$]. For the 350-ms SOA, the inhibitory effect emerged, reaching significance at Diff2 [$F(1,16) = 19.55$, $p<.01$]. At each of the four longest SOAs, the differences between Diff1 and Same, and between Diff2 and Same, were reliably greater than zero, confirming the presence of IOR [smallest $F(1,16) = 5.45$, $p<.03$]. As Figure 9a illustrates, the IOR effects found in the current study generally follow the curve of those found in prior experiments using this paradigm.

With respect to the spatial distribution of IOR over time (Figure 9b), the current study also is consistent with the results of Samuel and Weiner (2001) and Samuel and Kat (2003). The previous studies found a spatial gradient to IOR, with a greater difference from Same for targets farther away (Diff2) than those closer (Diff1), but only for about one second after target presentation. In the Preliminary Experiment, for the 350 and 700-ms SOAs, this difference reached significance [smaller $F(1,16) = 4.81$, $p<.05$]. In contrast, for SOAs beyond one second, the difference disappeared [1500-ms SOA, $F(1,16) = .08$, $p=.78$; 2500-ms SOA, $F(1,16) = .53$, $p=.48$; 3500-ms SOA, $F(1,16) =2.30$, $p=.15$]

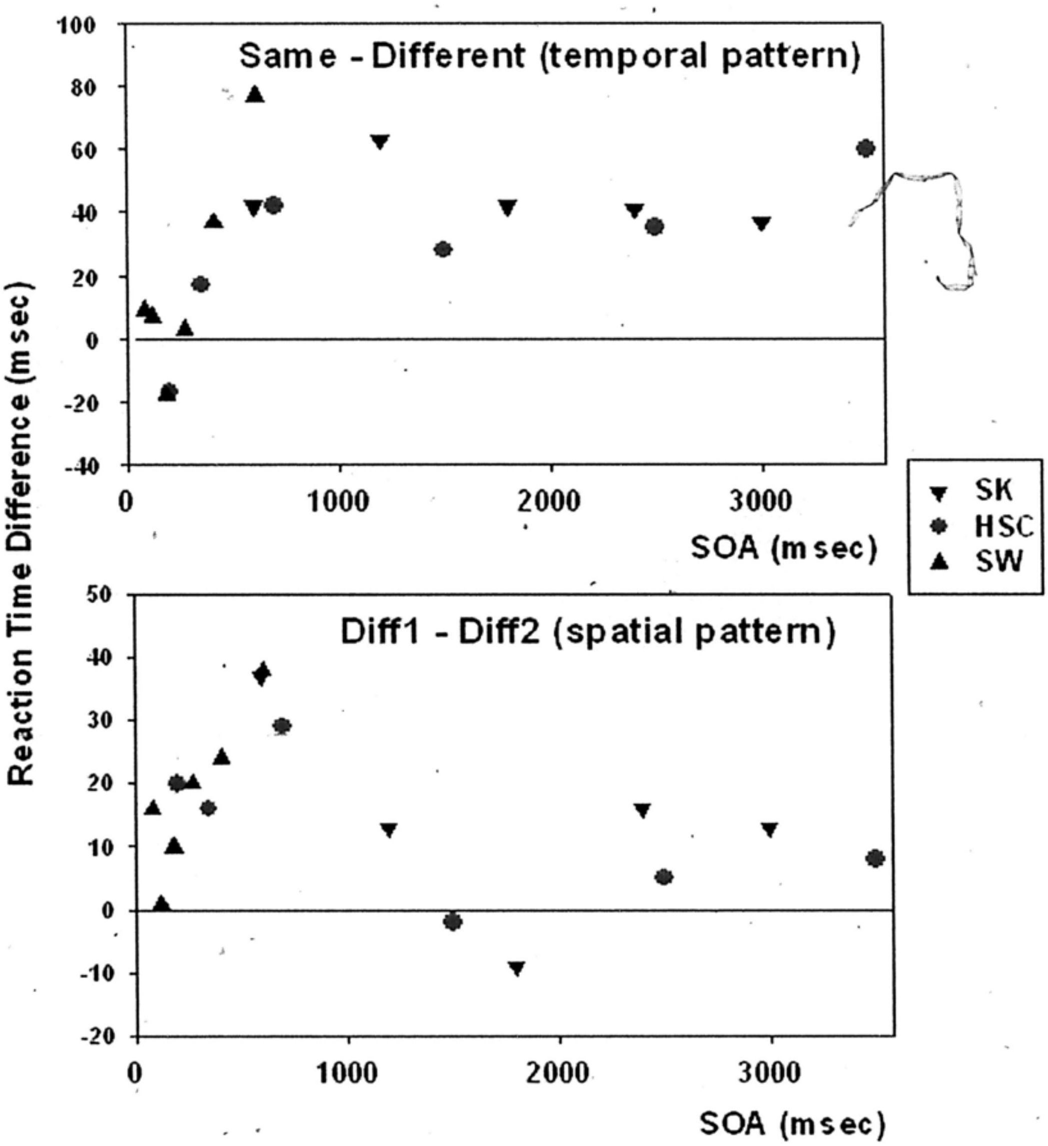

Figure 9. Top panel: IOR effects (difference in RT between Same and average of the two Diff locations), from Samuel & Weiner (2001; Experiment 1)[upward triangles], Samuel & Kat (2003; Experiment 1) [downward triangles], and the present study's Preliminary Experiment 1 [circles]. Bottom panel: Spatial differences in IOR (difference in RT between Diff1 location and Diff2 location); same symbols as top panel.

Having successfully established Samuel and Weiner's (2001) paradigm, we now proceed to use it to look for non spatial attribute-based inhibition of return in detection tasks.

Chapter 3: Non spatial-based IOR in detection tasks

The central aim of the present study is to look for the probable non spatial-based inhibition of return using these richer displays. If the effect is found, an additional aim is to specify the spatial and temporal properties of the special nonspatial attribute-based IOR. Chapter 3 provides tests of these issues.

Experiment 1: Color-based repetition effect

Experiment 1 looks for probable color-based inhibition of return using Samuel and Weiner (2001) paradigm. If the effect is found, an additional aim is to specify the spatial and temporal properties of this special attribute-based IOR.

The existing literature on color-based IOR is divided among generally negative findings (e.g. Kwak & Egeth, 1992) and the observation of small but significant effects when a neutral attractor is introduced (e.g. Law et al., 1995). However, even with a neutral attractor, there are suggestions that the observed effects may be due to a type of repetition blindness, rather than IOR, given the pattern of the effects over time (e.g., Fox & de Fockert, 2001; Taylor & Klein, 1998); there are also attribute-based effects that follow this time course, but do not seem to require a neutral attractor (e.g., Riggio et al., 2004). In short, it is currently quite unclear whether true inhibition of return can only be found in location-based tests, or if it also occurs for other attributes. Experiment 1a was designed to test whether robust color-based IOR, with more standard temporal properties, can be demonstrated by using richer stimulus displays.

Given the conflicting results in the existing literature, we also decided to test whether a neutral attractor would affect the size or likelihood of color-based IOR in more complex displays; Experiment 1b provides this test.

Experiment 1a

Method

Participants Twenty undergraduate and graduate students from Peking University were recruited. Ages ranged from 17 to 29 years (Mean = 22 years). All had normal or corrected-to-normal color vision, and were naïve to the purpose of the experiment. Participants were tested individually; each received 20 RMB for participating.

Apparatus and Procedure The apparatus was the same as in the Preliminary Experiment. The displays were similar, except that only two types of small figures were used: red circles and blue circles. See Figure 10 for an illustration of a typical trial. If there is color-based inhibition of return under these testing conditions, then target detection will be slower when the target is the same color as the cue (red-red, or blue-blue) than when the cue and target differ in color (blue-red, or red-blue).

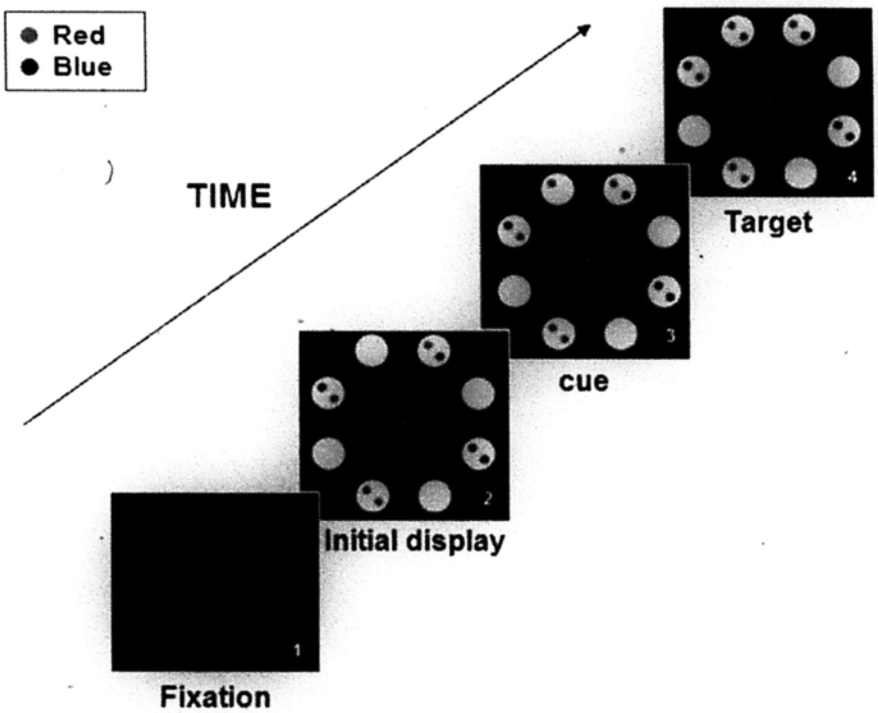

Figure 10. Example of the sequence of events for a sample trial in Experiment 1a (Note: not drawn exactly to scale; in the actual displays, each frame was a 480 x 640 pixel display).

Each participant was presented with three blocks of 160 trials. The 144 experimental trials within each block included the factorial crossing of six SOAs x four possible cue locations x three possible target conditions (Same, Diff1 and Diff2) x two possible color repetition conditions (repetition or non-repetition). There were also 16 catch trials per block, in which the cue appeared but no target followed; subjects were instructed not to respond on such trials. Given the number of trials in each block, we divided blocks into two passes, offering a rest period after each pass.

Results and Discussion

The data from one subject were not included in the analyses due to very slow reaction times (most RTs were much higher than 700 ms). One subject's data were excluded because of very high variance in reaction times. For the remaining 18 subjects, the miss rates and error rates were very low, averaging less than 1%. Figure 11 presents the reaction time data.

The mean correct reaction times were submitted to a three-way analysis of variance, with degrees of freedom corrected for violations of the sphericity assumption. The factors were Color Repetition (repeated vs. nonrepeated), SOA (200, 350, 700, 1500, 2500 and 3500 msec), and Location (Same, Diff1, and Diff2). The three-way interaction was significant [$F(10,167)=1.95$, $p<.05$], and this higher-order interaction influenced two of the two-way interactions: The interactions of Location x Color Repetition [$F(2,34)=9.49$, $p<.01$] and Location x SOA [$F(10,170)=2.76$, $p<.01$] were both significant. Note that the Location x SOA interaction is in part due to typical location-based IOR: Reactions times are much slower in the Same location than in the two Different locations, but not at the shortest SOAs. The interaction of SOA and Color Repetition did not reach significance [$F(5,85)=1.76$, $p=.13$]. All three main effects were significant [Color, $F(1,17)=4.72$, $p<.05$; SOA, $F(5,85)=16.54$, $p<.01$; Location, $F(2,34)=22.46$, $P<.01$].

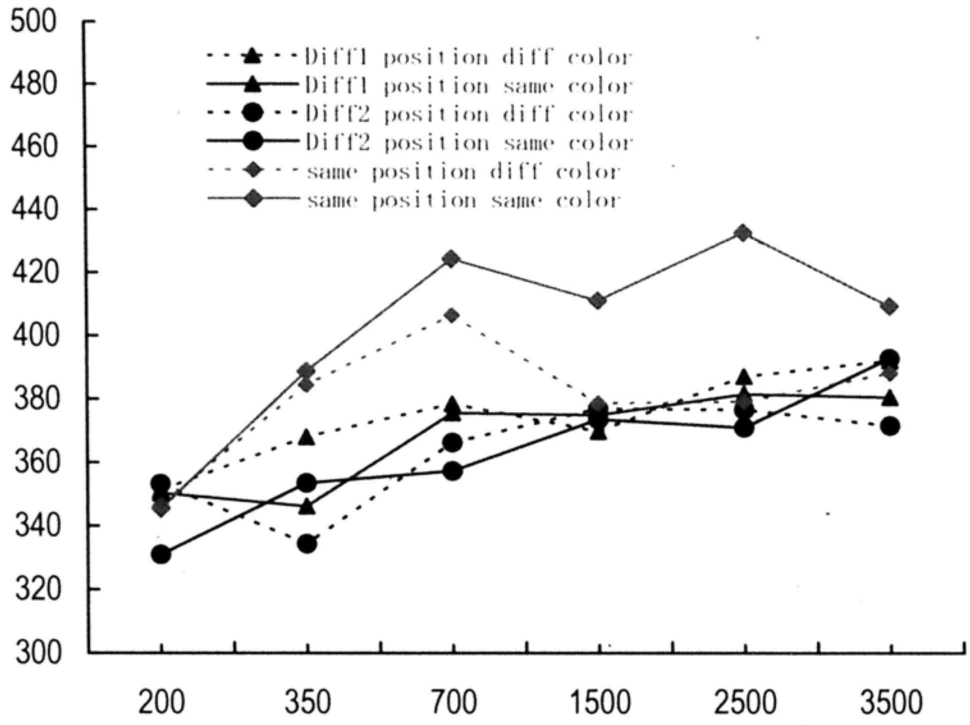

Figure 11. Experiment 1a: Target detection times, broken down by Color (repeated, nonrepeated), location (Same, Diff1 and Diff2) and stimulus onset asynchrony (SOA).

The significant three-way interaction reflects the presence of a color-based IOR effect, but one that differed across location. In particular, as Figure 11 shows, it is clear that color-based IOR occurred, but only in the "Same" condition: Target detection was impaired when the same color was recently cued, but only when the cue and target were in the Same location. This impression was confirmed by a set of simple comparisons conducted on the data from the Same condition. Consistent with the usual location-based IOR literature, there is no separation based on Color Repetition at 200 or 350 msec SOA. For SOA = 700 msec, the difference between "nonrepeated" and "repeated" color in the Same condition is 18 ms, a nonsignificant inhibitory trend. For the three longest SOAs (1500, 2500, and 3500 msec), color-based IOR in the Same location was robust (smallest $F(1,17)=7.42$, $p<.01$]. There was no hint of color-based IOR in either the Diff1 or the Diff2 locations. Note that both Kwak and Egeth (1992) and Riggio et al. (2004) reported (small but) significant color- or shape-based inhibitory effects that exhibited exactly the same restriction – the inhibitory effects were only observed when cue and target shared location.

The results of Experiment 1a indicate that with the richer displays used by Samuel and Weiner (2001) color-based IOR can produce robust effects that generally follow the time course of location-based IOR. There is some suggestion that the location-based effect may emerge slightly sooner (see Figure 11; also see the results of Experiment 1b below), but the general pattern is quite similar. Critically, the attribute-based effect does not appear to be independent of location, consistent with some smaller effects reported in previous studies using less complex displays. Experiment 1b again tests for color-based IOR in relatively rich displays, and in addition examines whether a neutral attractor plays an important role under these conditions.

Experiment 1b

As noted in the introduction, Law et al. (1995) argued that color-based IOR requires a neutral attractor, with that attractor serving to remove attention from the original cue. Law et al.'s data supported their suggestion, and other studies have also shown that under some circumstances the attractor does play an important role (e.g., Taylor & Klein, 1998; but see Riggio et al., 2004, for significant effects without the attractor). The results of Experiment 1a make it clear that color-based IOR can be observed in moderately complex displays without a neutral attractor. However, the prior results suggest that a neutral attractor could potentially affect the temporal and/or spatial properties of color-based IOR, and possibly lead to even larger effects. Thus, Experiment 1b employs the relatively rich displays used in Experiment 1a, and adds a neutral central attractor between the cue and target events.

Method

Participants Twenty two students participated in Experiment 1b. Thirteen were undergraduate and graduate students recruited from Peking University, and nine subjects were undergraduate students from the Chinese University of Hong Kong. Ages ranged from 17 to 33 years (Mean = 25 years). All had normal or corrected-to-normal color vision, and were naïve to the purpose of the experiment. They were tested individually. The students from Peking University were given 20 RMB for their participation, and the others received credit toward a requirement of a psychology course at the Chinese University of Hong Kong.

Apparatus and Procedure The apparatus was identical to that in Experiment 1a mentioned above. The procedure was also the same, except that a magenta-colored central cue was inserted. As Figure 12 shows, this involved a new 50-msec Frame 4, followed by a 30 msec interstimulus interval (Frame 5). In order to keep the SOAs matched to those of Experiment 1a, the cue times (Frame 3) were reduced by 80 msec (120, 270, 620, 1420, 2420 and 3420 msec).

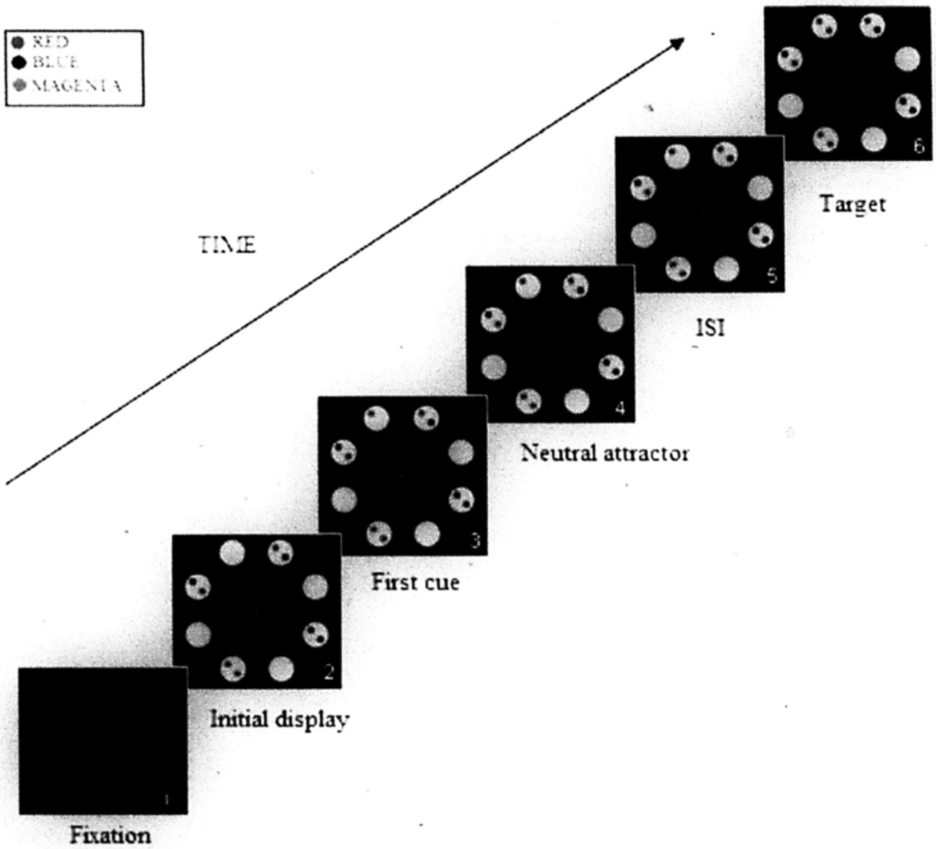

Figure 12. Example of the sequence of events for a sample trial in Experiment 1b (Note: not drawn exactly to scale; in the actual displays, each frame was a 480 x 640 pixel display).

Results and Discussion

We analyzed each subject's accuracy first. The data from three subjects were not included due to very high variance in the reaction times (during their debriefing, these three subjects reported that they had finished their Olympic games reception service training immediately before taking part in this experiment). One other subject's data were excluded due to extremely long reaction times (most RTs were much more than 700 msec). For the remaining 18 subjects, the miss rates and error rates were very low, averaging less than 1%.

Figure 13 shows the reaction time data. As in Experiment 1a, we conducted a three-way analysis of variance on the reaction times. Again, the critical three-way interaction was significant [$F(10,170)=2.09$, $p<.05$]. This higher-order interaction led to all of the two-way interactions reaching significance [Location x SOA, $F(10,170)=2.01$, $p<.05$; Location x Color Repetition, $F(2,34)=9.35$, $p<.01$; Color Repetition x SOA, $F(5,85)=3.09$, $p<.05$], with the Location x SOA interaction again also reflecting location-based IOR. All three main effects were also significant [SOA, $F(5,85)=2.46$, $p<.05$; Location, $F(2,34)=25.94$, $p<.01$; Color Repetition, $F(1,17)=8.07$, $p<.01$], with the effects of Location and Color Repetition apparently driven by the three-way interaction.

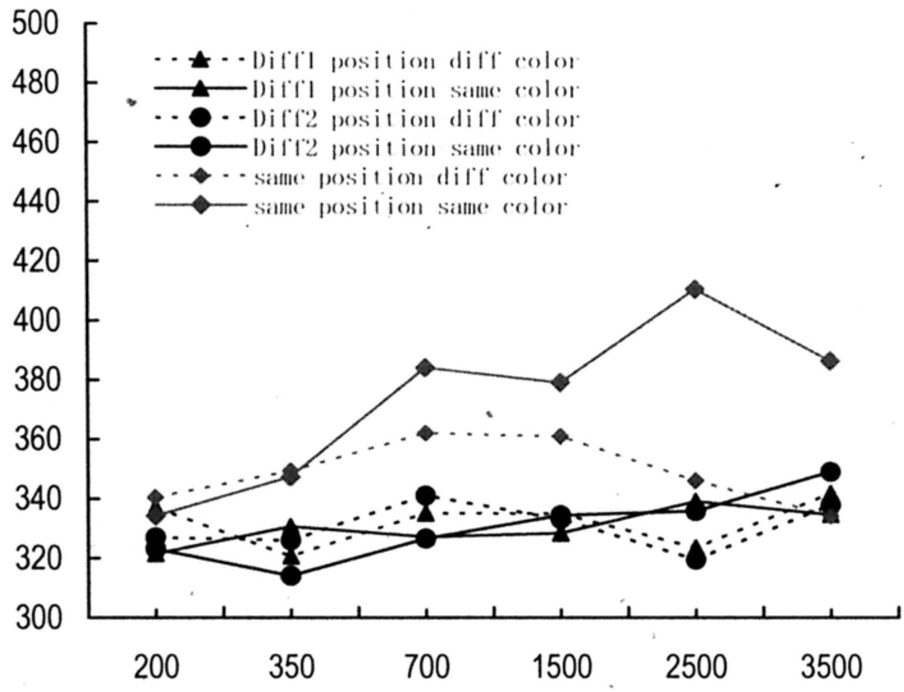

Figure 13. Experiment 1b: Target detection times, broken down by Color (repeated, nonrepeated), location (Same, Diff1 and Diff2) and stimulus onset asynchrony (SOA).

As in Experiment 1a, robust color-based IOR effects were found after the shortest SOAs, but only in the Same location, producing the three-way interaction. When the cue and target were in the Same location, the difference between "nonrepeated" and "repeated" color was significant [smallest $F(1,17)=5.16$, $p<.05$] for the four longest SOAs (700, 1500, 2500, and 3500 msec). Also as in Experiment 1a, there was no systematic inhibitory effect at the Diff1/Diff2 locations (there was actually a small facilitation effect at Diff1 at the 700 msec SOA [$F(1,17)=5.34$, $p<.05$], and an inhibitory one for the 2500 msec SOA [$F(1,17)=5.03$, $p<.05$]; no effects reached significance in the Diff2 location).

Summary of Experiment 1a,1b

Clearly, the results of Experiment 1a closely match those of Experiment 1b: The data in Figures 11 and 13 are extremely similar. An ANOVA comparing the two experiments indicates that the magnitude of the IOR in Experiment 1b is not significantly different from that of Experiment 1a. In both experiments we see slower responses when cue and target share color and location, beginning with the 700 msec SOA condition. The similarity across experiments suggests that the neutral attractor is not a necessary factor in eliciting color-based IOR (a similar conclusion was reached in spatial attribute studies by Pratt, O'Donnell and Morgan (2000) and Pratt (2002)). The systematic effects of a neutral adaptor found in some studies (e.g., Law et al., 1995; Taylor & Klein, 1998) indicate that there are conditions in which this manipulation matters, but with the more complex displays used in Experiments 1a and 1b, robust color-based IOR occurs without any obvious role for the attractor.

It seems plausible that attribute-based IOR (here, color-based IOR) requires that the attribute have sufficient distinctiveness (e.g. "RED" is very different from

"BLUE") to serve as a bias for inhibition. To test this speculation, we will conduct two experiments, manipulating the salience of the target to see whether the repetition effect requires that targets and distractors are distinct enough for inhibition to be applied to one selectively.

Experiment 2: Shape-based repetition effect

The results with the color attribute were sufficiently encouraging for us to go on to use Samuel and Weiner (2001)'s paradigm to test other attributes. Experiment 2 looks for probable shape-based inhibition of return using this richer display paradigm. As with color, if the effect is found, an additional aim is to specify the spatial and temporal properties of shape-based IOR.

Experiment 2a

Method

Participants Twenty seven undergraduate and graduate students from the Chinese University of Hong Kong were recruited. Ages ranged from 17 to 29 years (Mean = 22 years). All had normal or corrected-to-normal color vision, and were naïve to the purpose of the experiment. Participants received credit toward a requirement of a psychology course at the Chinese University of Hong Kong.

Apparatus and Procedure The apparatus was identical to that in Experiment 1a. The procedure was also similar, except that the stimuli varied in shape (filled circle and filled square), rather than color. See Figure 14 for an illustration of a typical trial. If there is shape-based inhibition of return under these testing conditions, then target detection will be slower when the target is the same shape as the cue (circle-circle, or square-square) than when the cue and target differ in shape (square-circle, or circle-square).

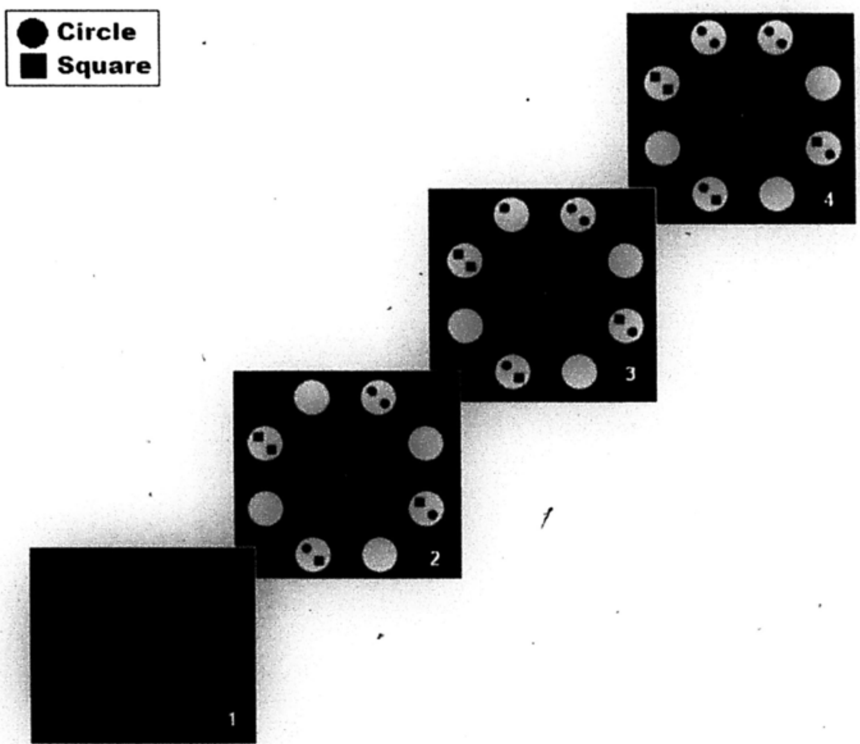

Figure 14. Example of the sequence of events for a sample trial in Experiment 2a (Note: not drawn exactly to scale; in the actual displays, each frame was a 480 x 640 pixel display).

Results and Discussion

Similar analysis steps were employed. First, we analyzed each subject's response accuracy. One subjects' data were excluded due to extremely long reaction times and high variance. All response times less than 100 ms or greater than 1500 ms were removed as outliers prior to analysis. For the remaining 26 subjects, the miss and error rates were very low, averaging less than 1%.

Figure 16 presents the mean target detection times, broken down by the location of the target. Overall, targets were responded to relatively quickly, with a mean reaction time of 381.15 ms.

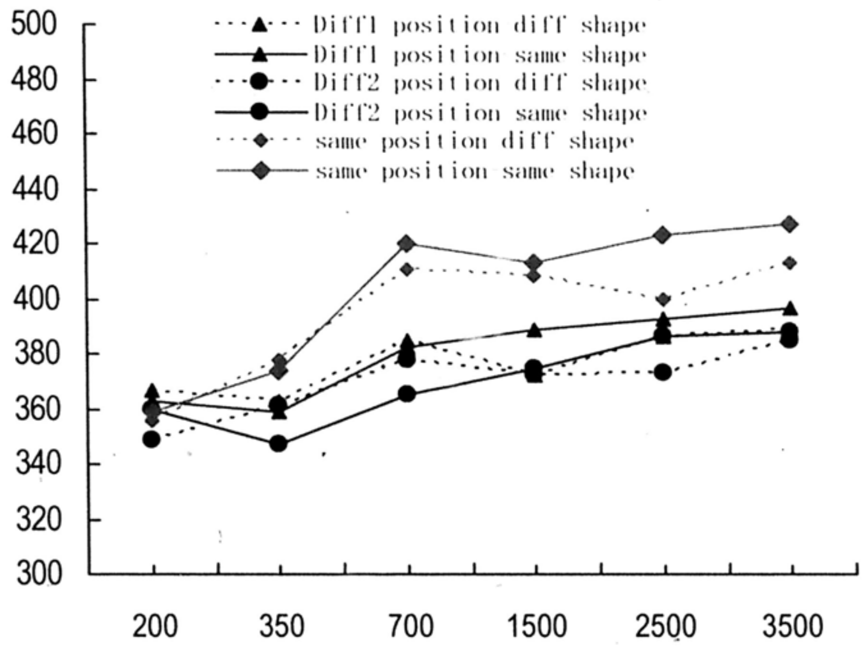

Figure 15. Experiment 2a: Target detection times, broken down by Shape (repeated, nonrepeated), location (Same, Diff1 and Diff2) and stimulus onset asynchrony (SOA).

The mean correct reaction times were submitted to a three-way analysis of variance, with degrees of freedom corrected for violations of the sphericity assumption. The three factors were as Shape Repetition (repeated vs. nonrepeated), SOA (200, 350, 700, 1500, 2500 and 3500 ms), and Location (Same, Diff1 and Diff2). Unlike the factor Shape [$F(1,25)=2.61$, $P>.05$)], both of the SOA and the Location main effect were significant [$F(5,125)=28.21$, $P<.01$; $F(2,50)=52.85$, $P<.01$]. The elevated reaction times for the same condition (see Figure 15) show that the location-based IOR appeared. But in contrast to the results in Experiment 1a and 1b with color, no significant shape-based IOR appeared. This conclusion was supported by the two-way and three-way interactions. The three-way interaction was not significant [F(10,250)=.65, p>.05]. For the two-way interactions, except that SOA x Location was significant [F(10,250)=4.02, p<.01], neither SOA x Shape nor Shape x Location reached significance [SOA x Shape, F(5,125)=1.78, p>.05; Shape x Location, F(2,50)=.97, p>.05]. Note that the significant Location x SOA interaction is in part due to typical location-based IOR, that is, reaction times are much slower in the Same location than in the two Different locations, but the effect was not significant at the shortest SOAs, which is consistent with typical location-based IOR. It should be noted that small difference (weak shape-based IOR) at 700, 1500, 2500 and 3500 ms SOA in the "Same" conditions (and the small difference at 1500, 2500 and 3500 ms SOA in the "Diff1" conditions) did not reach significance. The existence of this trend actually suggests that there might be some weak shape-based IOR, but with the poor discriminability of the filled circle/square, the effect is too weak to reach significance.

In sum, no shape-based IOR appeared in this experiment (Experiment 2a) arrangement. The combined evidence from Expts 1 and 2a help to confirm this speculation: the inhibitory effect requires that targets and distractors are distince enough for inhibition to be applied to one selectively. This possibility will be addressed further below.

Experiment 2b

Experiment 2a provides the most direct test of whether the salience between target and distractor is a critical factor for the non-spatial attribute-based IOR's development. We will use the filled circle and open square as the stimuli, instead of the small different ones, filled circle and filled square.

Method

Participants Twenty seven undergraduate and graduate students from the Chinese University of Hong Kong were recruited. Ages ranged from 18 to 25 years (Mean = 20 years). All had normal or corrected-to-normal color vision, and were naïve to the purpose of the experiment. Participants received credit toward a requirement of a psychology course at the Chinese University of Hong Kong.

Apparatus and Procedure The apparatus was identical to that in Experiment 2a. The procedure was also the same, except that the stimuli were shapes that are more discriminable (filled circle and open square) than the shapes used in the previous experiment. See Figure 16 for an illustration of a typical trial. If there is shape-based inhibition of return under these testing conditions, then target detection will be slower when the target is the same shape as the cue (circle-circle, or square-square) than when the cue and target differ in color (square-circle, or circle-square). The procedure was the same as that in the Experiment 2a.

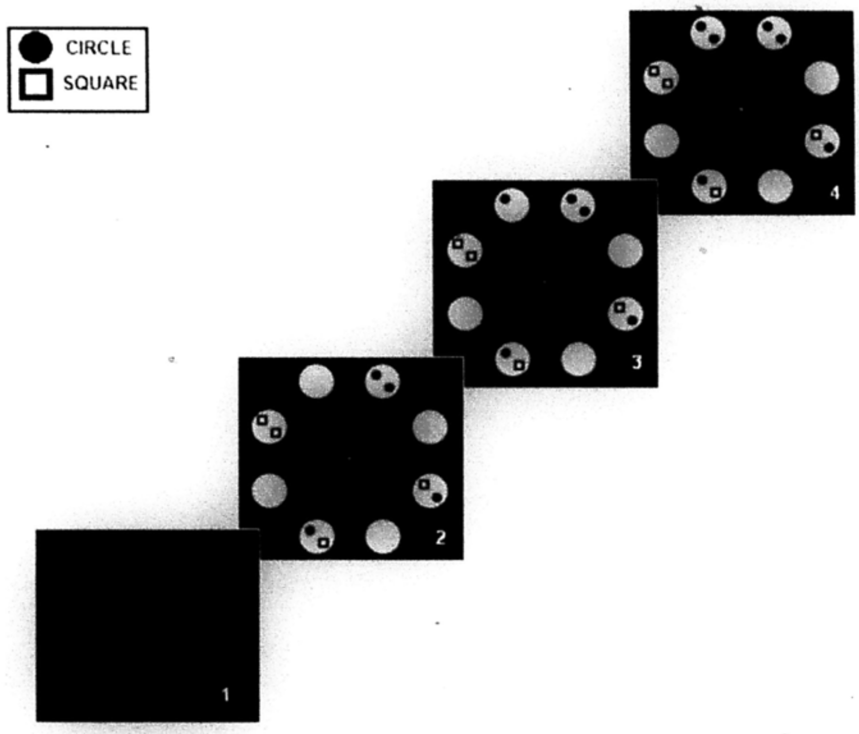

Figure 16. Example of the sequence of events for a sample trial in Experiment 2b (Note: not drawn exactly to scale; in the actual displays, each frame was a 480 x 640 pixel display).

Results and Discussion

The primary analysis concerned whether the shape-based IOR appeared under this special experimental arrangement. We first analyzed each subject's response accuracy. Three subjects' data were excluded because of very high variance in reaction times and higher error rates (more than 8%). For the remaining 24 subjects, the miss and error rates were very low, averaging less than 1%. For further analysis, the response times less than 100 ms or greater than 1500 ms were removed as outliers prior to analysis.

Figure 17 presents the mean target detection times, broken down by the location of the target. Overall, targets were responded to relatively quickly, with a mean reaction time of 395 ms.

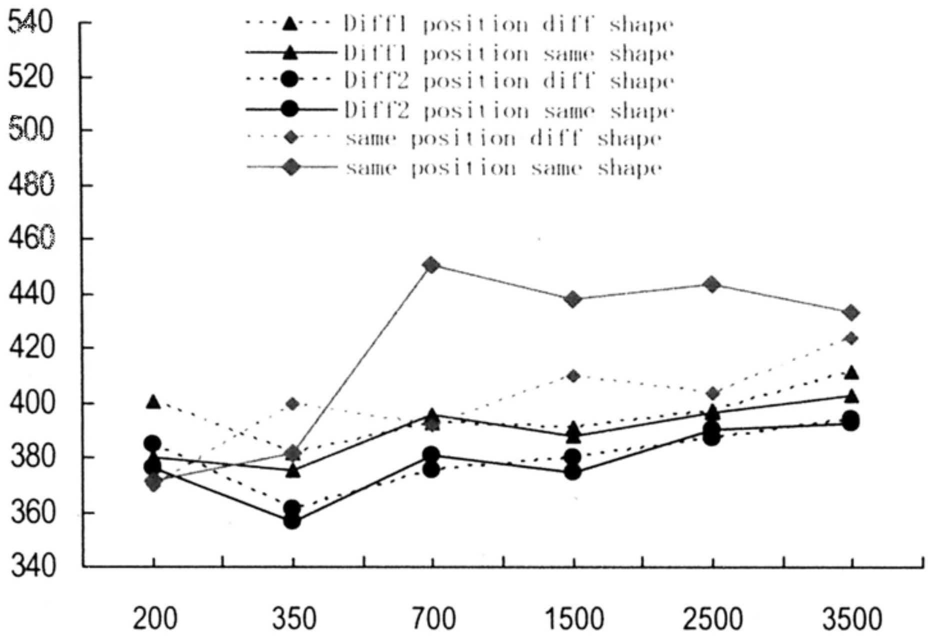

Figure 17. Experiment 2b: Target detection times, broken down by Shape (repeated, nonrepeated), location (Same, Diff1 and Diff2) and stimulus onset asynchrony (SOA).

The mean correct reaction times were submitted to a three-way analysis of variance, with degrees of freedom corrected for violations of the sphericity assumption. The three factors were as Shape Repetition (repeated vs. nonrepeated), SOA (200, 350, 700, 1500, 2500 and 3500 ms), and Location (Same, Diff1 and Diff2). The three-way interaction was significant [$F(10,230)=2.21, P<.05$], influencing the three two-way interactions: SOA x Location [$F(10,230)=4.49$, $P<.01$], SOA x Shape [$F(5,115)=5.53$, $P<.01$) and Location x Shape [$F(2,46)=8.53$, $P<.01$]. Among them, the significance of Location x SOA interaction indicated significant location-based IOR happened at the longer SOAs. All three main effects were significant [Shape, $F(1,23)=4.42$, $P<.05$; Location, $F(2,46)=23.81, P<.01$; SOA, $F(5,115)=10.45$, $P<.01$].

The significance of the three-way interaction indicates the presence of a shape-based IOR effect that differed across locations. As Figure 17 shows, robust shape attribute-based IOR effects were found after the shortest SOAs, but were limited in the Same location. This conclusion was supported by a set of simple comparisons conducted on the data from the three conditions. For the three SOAs (700, 1500 and 2500 ms), shape-based IOR in the Same condition was robust [smallest $F(1,23)= 5.13$, $P<.05$]. At SOA 3500 ms, the inhibitory effect appeared but did not reach significance. As to Diff1 and Diff2 conditions, no significant repetition effects appeared in each of the SOAs except a facilitatory effect appeared at the 200 ms SOA under Diff1 condition [$F(1,23)=6.75$, $P<.05$].

Summary of Experiment 2a,2b

Clearly, the results of Experiment 2b are much more like those of Experiment 1: The data in Figures 11,13 and 17 are quite similar. In Experiment 1a and 1b we saw slower responses when the cue and target shared color and location, beginning with the 700 msec SOA condition; Experiment 2b shows a comparable result for shape. The similarity across experiments further suggests that the neutral attractor is not a necessary factor in eliciting attribute-based IOR. With the more complex displays used in our experiments, robust attribute-based IOR occurs without any obvious role for the attractor.

However, in the Experiment 2a which used two filled shapes, no IOR appeared. With one filled shape and one open shape in Experiment 2b, the results totally changed, that is, robust IOR appeared. The pattern of results suggests that perceptual salience affects the occurrence of IOR. With two filled shapes, the perceptual salience was not sufficient to provide any shape-based coding, hence no attribute-based IOR was generated. But with one open and one filled shapes, the items are noticeably different (as is the difference between Red and Blue), and attribute-based IOR occurs. Experiment 2b complements the color-based experiments, and leads to the suggestion that if the stimuli offer featural differences that are salient enough, the perceptual system uses them to encode the displays, and IOR can be applied to those features. From this perspective, one reason that location-based IOR has been easier to observe is that the feature (location) is extremely salient.

In a very recent article, Dukewich (2009) predicted that IOR will be more pronounced if the cues are less salient. Obviously, this prediction is at odds with the data in the current experiments. In that article, the author attempted to reconceptualize inhibition of return as habituation of the orienting response. Since "the role of habituation in IOR is along a single dimension: space (Dukewich, P242)", it is possible that habituation operates on this special level and only some close related feature (s) of a stimuli will habituated. It seems that his prediction/reasoning is more specifically to habituate characteristics (e.g. the intensity of the habituating stimulus). Besides, the author himself also acknowledges till now no studies that have looked at the effects of cue salience on IOR.

Experiment 3: Orientation-based repetition effect

The results for color and shape led us to test whether the orientation of an object is salient enough to produce attribute-based IOR. Among the different features, very few studies have been done with orientation-based IOR. Laarni et al. (1996) reported that orientation can be identified earlier if targets are cued by location rather than color. Experiment 3 looks for an orientation –based (left 45^0 and right 45^0 orientation) repetition effect using rich displays. If the effect is found, an additional aim is to specify the spatial and temporal properties of orientation-based IOR.

Method

Participants Twenty three undergraduate and graduate students from the Chinese University of Hong Kong were recruited. Ages ranged from 18 to 26 years (Mean = 22 years). All had normal or corrected-to-normal color vision, and were naïve to the purpose of the experiment. Participants received credit toward a requirement of a psychology course at the Chinese University of Hong Kong.

Apparatus and Procedure The apparatus was identical to that in Experiment 2. The procedure was also the same, except that the stimuli varied in orientation (left and right 45 degree tilted lines), rather than color or shape. See Figure 18 for an illustration of a typical trial). If there is orientation-based inhibition of return under these testing conditions, then target detection will be slower when the target is the same orientation as the cue (left orientation -left orientation , or right orientation - right orientation) than when the cue and target differ in orientation (right orientation - left orientation, left orientation - right orientation).

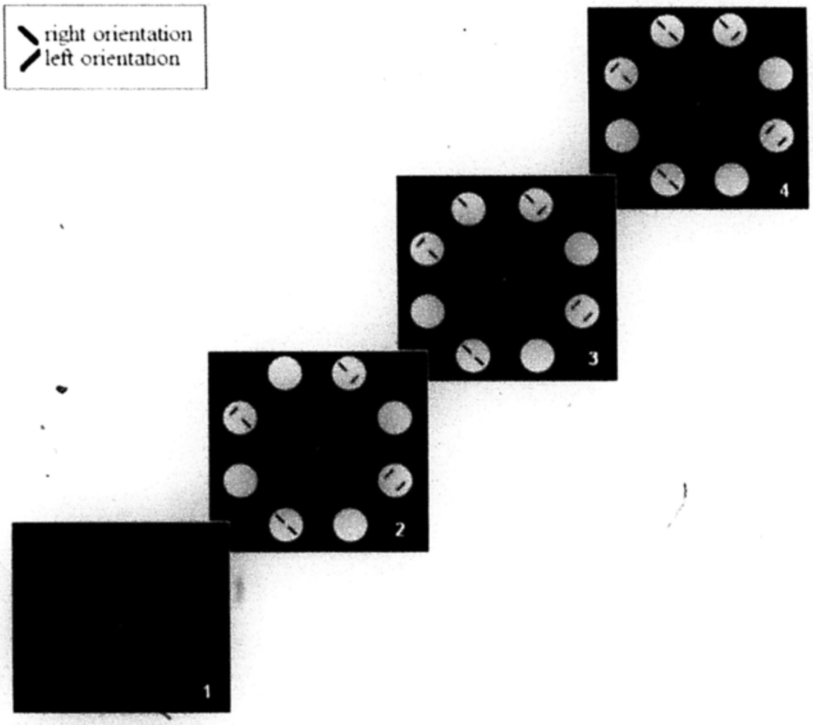

Figure 18. Example of the sequence of events for a sample trial in Experiment 3 (Note: not drawn exactly to scale; in the actual displays, each frame was a 480 x 640 pixel display).

Results and Discussion

We first analyzed each subject's response accuracy. Two subjects' data were excluded because of very high variance in reaction times and high error rates (more than 8%). For the remaining 21 subjects, the miss and error rates were very low, averaging less than 1%. For further analysis, response times less than 100 ms or greater than 1500 ms were removed as outliers prior to analysis.

The mean correct reaction times were submitted to a three-way analysis of variance, with degrees of freedom corrected for violations of the sphericity assumption(see Figure 19). In this experiment, three factors were involved: Orientation Repetition (repeated vs. nonrepeated), SOA (200, 350, 700, 1500, 2500 and 3500 ms), and location (Same, Diff1, and Diff2). The analysis indicated that the three-way interaction was not significant [F(10,200)=.65, n.s.]. Only the two-way interaction effect of SOA x Location was significant [SOA x Location, F(10,200)=2.56, P<.01; SOA x Orientation, F(5,100)=.52, n.s.; Location x Orientation, F(2,40)=1.95, n.s.] and this significance reflected location-based IOR. The main effect of Orientation Repetition was not significant, F(1,20)=.94, n.s. The other two main effects were significant [SOA, F(5,100)=10.50, P<.01; Location, F(2,40)=40.62, P<.01], as components of the location-based IOR effect

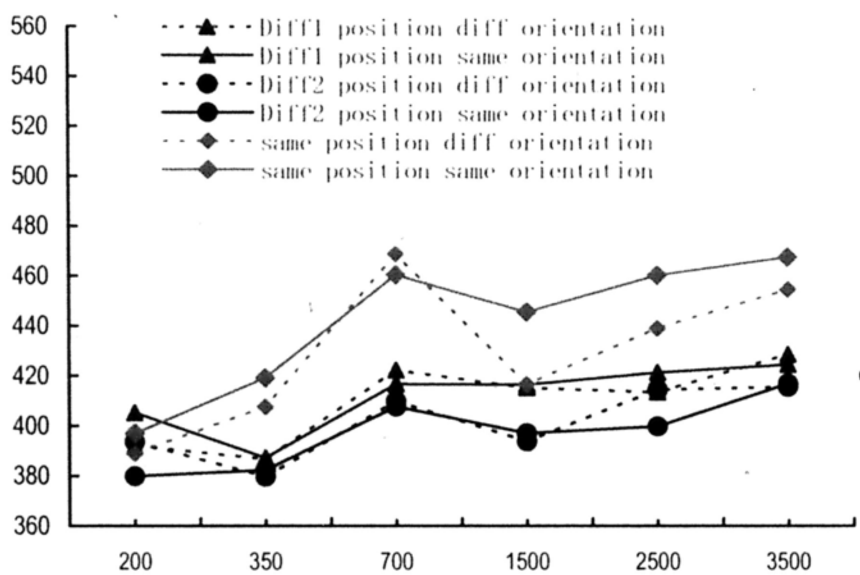

Figure 19: Target detection times, broken down by orientation (repeated, nonrepeated), location (Same, Diff1 and Diff2) and stimulus onset asynchrony (SOA).

In the Same condition, an inhibitory trend did emerge, especially from SOA 1500 ms, though the orientation–based IOR did not quite reach statistical significance. It is possible that the 45^0 left and right orientations in our displays did not differ saliently enough and these feature differences did not provide very good encoding (and thus weak IOR). If so, the failure to obtain a robust attribute-based IOR further supports the proposal that the feature differences are one of the critical factors in inducing attribute-based IOR.

Summary of Experiment 1-3

To date, relatively few studies have been done on the non-spatial attribute-based inhibitory effect. The goal of the experiments in Chapter 3 of this thesis was to examine non-spatial attributes, including color, shape and orientation, to see if they produce a repetition effect in simple detection tasks.

In all of the experiments, robust location-based IOR appeared: reaction times were much slower in the same location than that in the two different locations, but not at the shortest SOAs. This finding leads to the conclusion that the location is very important in visual search. As we noted above, when the stimuli provided sufficient attribute-based coding, then attribute-based IOR could develop. The results provide at least tentative support for this principal hypothesis. In our study, colors (red, blue) and shapes (filled circle, open square) offered feature difference that were salient enough for the perceptual systems to make use of these to encode the displays. Hence IOR could be applied to them. We found that nonspatial attribute-based IOR follows a time course very similar to that for location-based IOR (see Figures 20). If only location, another attribute, is salient (e.g. in the orientation experiment and the first shape experiment), then we only can observe location-based IOR.

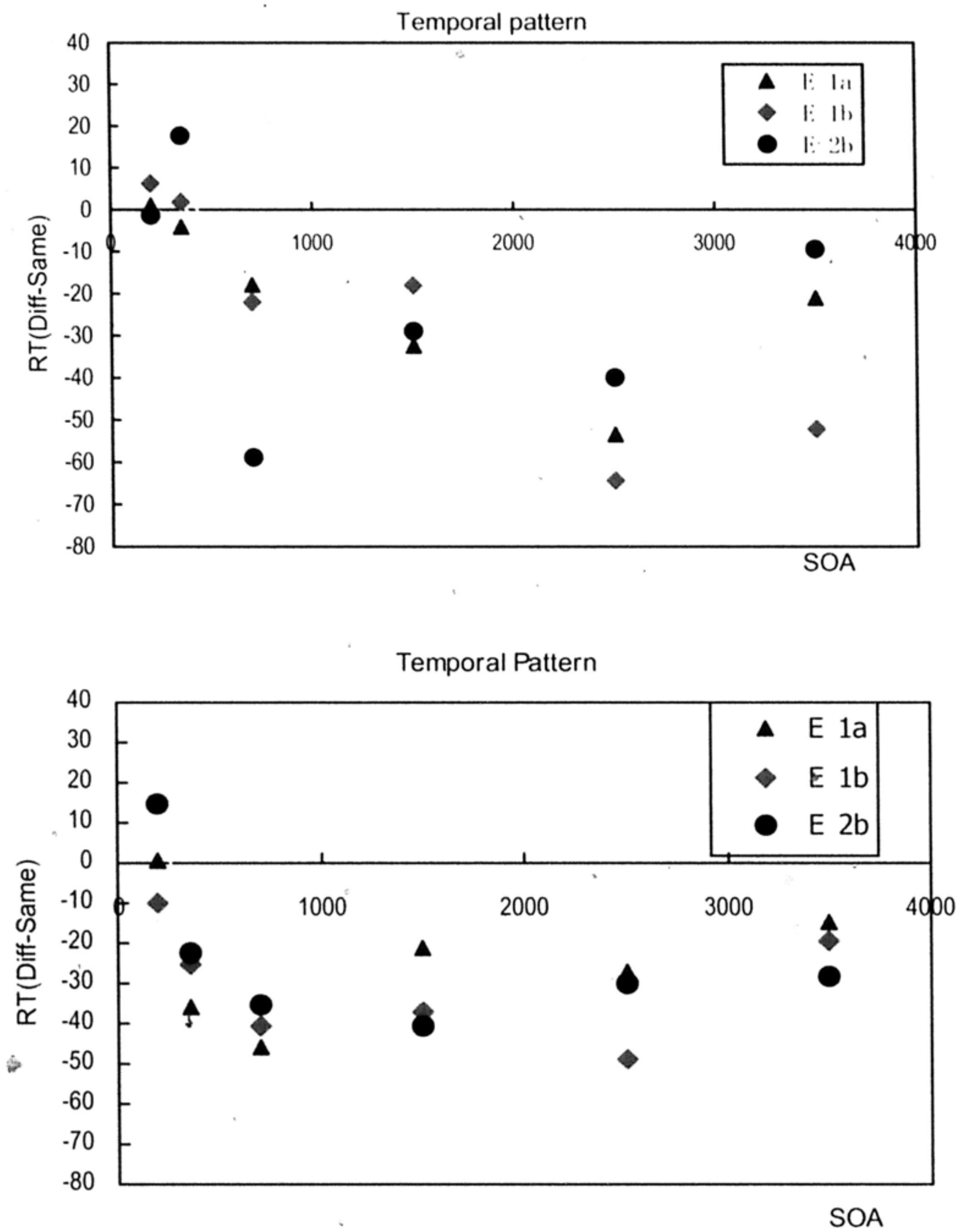

Figure 20: Summary of the attribute-based IOR and location-based IOR (E1a: Experiment 1a; E1b: Experiment 1b; E2b: Experiment 2b).Top panel: Temporal pattern of the nonspatial IOR (Unced – Cued). Bottom panel: Temporal pattern of the location IOR (Uncued – Cued). X axis: SOA (msec); Y axis: RT(Diff attribute-Same attribute) (msec).

We observed a robust location-based effect of inhibition which was consistent with our previous report and with the current literature on temporal aspects (see Figure 20 Bottom panel). Clearly, in attribute-based tasks, the location-based IOR followed the general start point but existed at least until 3500 ms. As to the spatial aspect, according to the results reported above, most differences emerged before 1000 ms SOA. For the location-based IOR, in the experiments reported above, the spatial aspect is not clear, but most difference primarily happened before 1000 ms SOA.

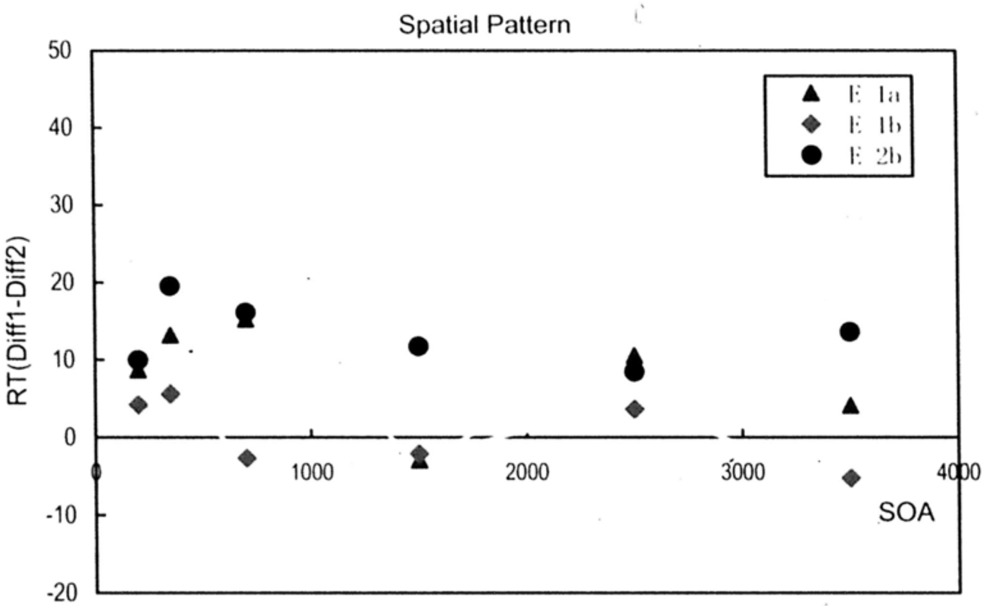

Figure21: Summary of the spatial property of the location-based inhibitory effect (Diff1-Diff2) (E1a: Experiment 1a; E1b: Experiment 1b; E2b: Experiment 2b). X axis: SOA (msec); Y axis: RT(Diff attribute-Same attribute) (msec)

Given that an attribute-based effect of inhibition was observed in the detection tasks used in Experiment 1-3, it is worthwhile to consider whether this kind of attribute-based IOR would be affected by task difficulty.

Chapter 4: Non spatial-based repetition effect in discrimination tasks

In the studies which have examined the time course of nonspatial attribute-based IOR, most researchers employed simple detection tasks. As was mentioned in the introduction, it is not universally true that inhibition following early facilitation for target discriminations. Actually, early researchers assumed that location-based IOR does not occur in discrimination tasks: "an IOR effect on choice RTs has been observed only in tasks requiring a saccadic or manual localization response" (Muller & Muhlenen, 1996). For example, Egly et al. (1992) (cf. from Lupianez et al. 1997) and Terry et al. (1994) used a shape discrimination task and failed to find any shape-based IOR. Other studies, such as those that used color discrimination tasks (Kingstone & Gazzaniga,1992, cf. from Klein & Taylor, 1994; Tanaka & Shimojo,1996), those that used orientation, vernier and luminance discrimination tasks (Tanaka & Shimojo, 1996), and those used size discrimination tasks (Tanaka & Shimojo, 1996) all failed to observe IOR. It seems these results did cast doubt on IOR as a general attentional phenomenon. But since Terry et al. (1994), there are several articles, such as Danziger, Kingstone and Snyder (1998), Handy, Jhy and Mangun (1999), Lupianez et al. (1997), Pratt (1995), Pratt and Abrams (1999) and Pratt, Kingstone and Khoe (1997), reporting that IOR can be obtained for the discrimination of target identity and orientation.

According to Taylor and Donnelly (2002), there are 4 types of paradigms used to study IOR: cue-target paradigm (which we described above), continuous-responding paradigm (only the target stimulus is presented on each trial, participants are required to respond to each target), target-target paradigm (conceptually similar to the continuous-responding paradigm) and non-response-target paradigm (similar to the cue-target paradigm, except that a response is required only to the second of the two targets). Regardless of the paradigms used, the study of IOR in target discrimination tasks can be categorized further according to the relationship between the discrimination that is made and the response used to report the result of that discrimination. One type is to determine whether an onset is the target or not and the execution response is to confirm the presence of the target. This belongs to occurrence discrimination experiments. Another class of tasks is object discrimination tasks. In these experiments, the response is to report the result of a perceptual discrimination, but not only the simply response or location of a discriminated target. According to review by Taylor and Donnelly (2002), there have been a limited number of paradigms employed for this type of discrimination, and moreover, the results produced are mixed.

The present set of experiments was designed to address two issues regarding the attribute-based repetition effect. The first issue related to the question: does attribute-based IOR occur in attribute discrimination tasks? By using the moderately complex paradigm of Samuel & Weiner (2001), we were able to observe attribute-based IOR in simple detection tasks. In the discrimination experiments described below, we matched the SOAs and other procedural aspects to those in the detection experiments described above.

The second issue was to address, if the repetition effect appears (non-spatial based IOR, location-based), is what the spatial distribution of the inhibitory effect looks like.

General Methods

Participants

Fifty four undergraduate and graduate students from the Peking University were recruited. Ages ranged from 16 to 33 years (Mean = 22 years). By self-report, all had normal or corrected-to-normal color vision, and were naïve to the purpose of the experiment. All were right-handed. They were divided for three experiments[i]. Each experiment was about 45-60 min in duration.

Apparatus and Procedure

In the experiments described in this chapter, we adopted the discrimination task. Apart from this change, the apparatus and stimuli were identical to the related attribute-based repetition experiments. In detail, for the color experiment, stimuli were the red and blue circles; for the shape experiment, stimuli were the open square and filled circle; for the orientation experiment, stimuli were the left 45 degree orientation line and right 45 degree orientation line. In all the discrimination tasks, no central cue (neutral cue) was inserted, and no catch trials were used. Each participant was presented with three blocks of 144 trials, which included the factorial crossing of

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[i] We originally arranged each experiment with 19 subjects. For Experiment 5 (shape experiment), we initially adopted the Experiment 2a (filled circle and filled square) method and ran it with 3 subjects. After reviewing the data from Experiment 2a and 2b, we immediately stop to use the Experiment 2b (filled circle and open square) stimuli arrangement. So Experiment 4 and Experiment 6 involved 19 participants, but Experiment 5 involved 16 participants.

six SOAs x four possible cue locations x three possible conditions (Same, Diff1 and Diff2) x two possible attribute repetition conditions (repetition vs. non-repetition). We divided blocks into two passes, offering a rest period after each pass.

The participants were asked to make a two alternative forced choice (2AFC) by pressing a button for all the tasks. For the color discrimination experiment, the (left) "N" key on the keyboard was pressed in response to a red target regardless of the target location, and the (right) "L" key was to be hit if the target was blue regardless of its location. For the shape discrimination task, the "N" key was hit in response to the circle shape and the "L" key was for square shape, again regardless of the location of the target. Similarly for the orientation experiment, "N" was for the left orientation while "L" was for the right orientation. Subjects were tested individually in a darkened, sound attenuated room. In this set of studies, the task requires participants to discriminate the targets, then give the right response. If there is attribute-based inhibition of return in discrimination, responses will be slower when the target is the same as the cue.

The data will be analyzed in terms of the different conditions between the cue and the target. RTs in error trials will be eliminated from the data analysis.

Experiment 4: Color-based repetition effect

Results

Errors occurred on less than 1% of all trials and these trials were excluded from the analysis. Among the 19 subjects, three subjects were removed because of very high variance in reaction times. For the remaining 16 participants, the response times less than 100 ms or greater than 1500 ms were removed as outliers prior to analysis.

To examine the color-based repetition effects, the mean RTs were analyzed with a 2 (color repetition: repeated vs. non repeated) x 6 (cue time: 200, 350, 700, 1500, 2500 and 3500 ms) x 3 (location situations: Same, Diff1 and Diff2) analysis of variance (ANOVA) (see the Figure 22). There was a significant main effect of Color repetition, $F(1,15)=31.66$, $P<.01$, with faster RTs for targets with the same color condition relative to targets with the different color (see the consistently higher dotted lines than solid lines in Figure 22). In addition, there was a significant main effect of Location, $F(2,30)=10.01$, $P<.01$, indicating that there was a difference in the magnitude of RTs across the cued and uncued locations. The main effect of SOA was not significant [$F(5,90)=1.26$, n.s.]. The two-way interaction Location x Color was not significant [$F(2,30)=.96$, $P>.05$], but the interactions of Location x SOA and Color x SOA were significant [For the former, $F(10,150)=3.54$, $P<.01$; for the latter, $F(5,75)=5.25$, $P<.01$]. The three–way interaction effect was not significant [$F(10, 150)=.51$, $P>.50$].

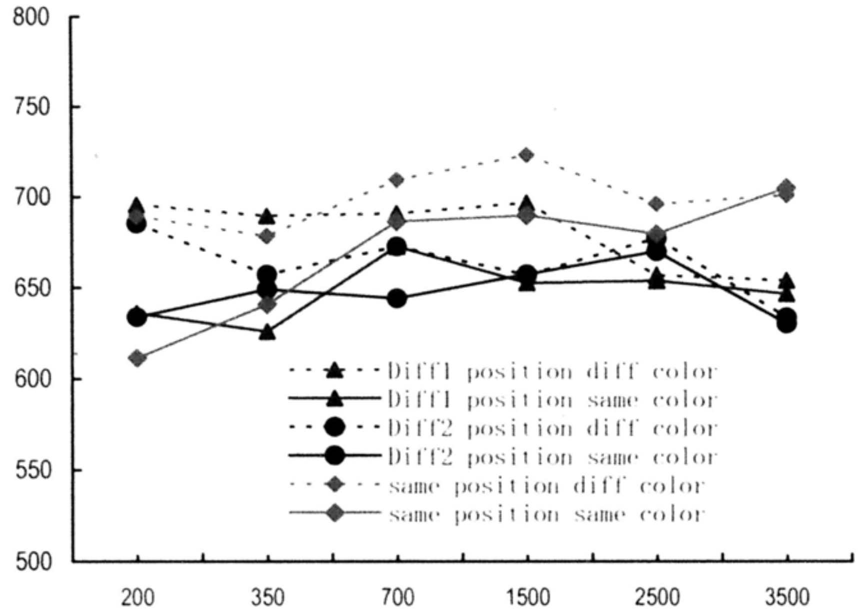
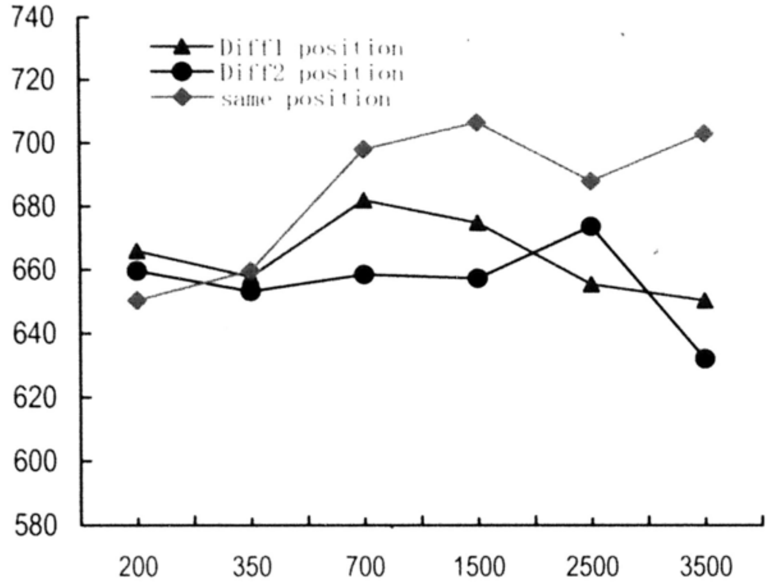


Figure 22: Target detection times, broken down by Color (repeated, nonrepeated), location (Same, Diff1 and Diff2) and stimulus onset asynchrony (SOA).

The significance of the Location x SOA interaction effect reflected location-based inhibition of return, which is similar with that observed in Preliminarily Experiment above though it developed some late until 700 ms SOA (see the figure 23 top panel). As to the Color x SOA effect, further analysis showed there was a difference in the magnitude of RTs for the color repetition and non repetition conditions across the SOAs (see the figure 23 bottom panel). A significant facilitatory trend appeared since SOA 200 ms to 2500 ms [at SOA 200, 350 and 1500 ms, the facilitatory effect reached significance, the smallest $F(1,15)=16.83$, $P<.01$; at SOA 700 ms, $F(1,15)=2.87$,n.s.]. Clearly, no inhibitory effect appeared in this color discrimination task.



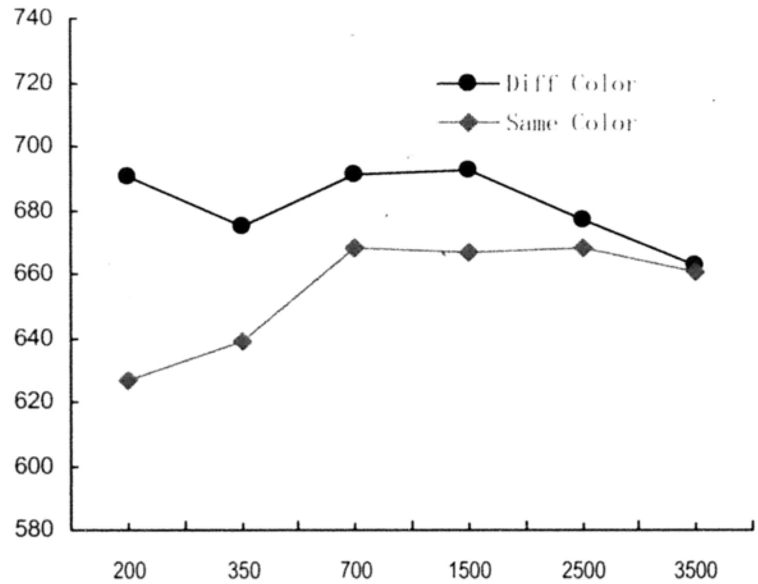


*Figure 23.*Top panel: figure for the Location x SOA interaction; Bottom panel: figure for the Color x SOA interaction. X axis: SOA (msec); Y axis: RT(target response times) (msec)

Discussion

This experiment employed a discrimination task, and the color repetition effect was quite different from that in the color detection experiment. It is clear that the disadvantage for repetition of the same color in a cued peripheral location that was found in the simple detection task did not appear here. In fact, we observed a tendency for facilitation in repeated color trials (FOR) at most of the tested SOAs.

In addition, we observed a typical location-based IOR effect in this discrimination experiment. As far as we know, Terry et al. (1994) were the first to study IOR with discrimination tasks. They did not find IOR in their discrimination tasks, though the task that they used was a type of occurrence discrimination (Taylor & Donnelly, 2002). In an influential discrimination IOR paper (Lupianez et al. 1997), using the cost-benefit paradigm (Posner, 1980), the authors reported some consistent results when the cue was a box flickering, and the targets were Red and Yellow. IOR within their discrimination task appeared within the SOA range of 700- to 1000- ms. The inhibitory effect in discrimination tasks not only dissipated faster than that in simple detection tasks, but also accrued inhibition more slowly. However, in our moderately complex displays, the inhibiton-based effect seems to last longer.

Our results suggest that perhaps with more demanding tasks, observers allocate more attention to locations rather than to other attributes (features); hence in this situation, IOR is predominantly location-based.

Experiment 5: Shape-based repetition effect

Results

Among the 16 subjects, the miss and error rates were very low, averaging less than 1%. For further analysis, the response times less than 100 ms or greater than 1500 ms were eliminated as outliers from the analysis. The mean RTs were analyzed with a 2 (Shape Repetition: repeated vs. nonrepeated) x 6 (SOAs: 200, 350, 700, 1500, 2500 and 3500 ms) x 3 (Location situations: Same, Diff1, and Diff2) ANOVA. The results were similar to those for the color repetition effect (see Figure 24). No three-way interaction appeared [F(10,150)=.83, n.s.], but two of the two-way interactions were significant [for SOA x Location, F(10,150)=3.18, P<.01; for SOA x Shape, F(5,75)=6.79, P<.01] (Figure 25 presents the two significant two-way interactions). The two-way interaction of Location x Shape did not reach significance [F(2,30)=.14, n.s.]. There was a significant main effect of SOA, F(5,75)=2.70, P<.05; a significant main effect of Location, F(2,30)=6.22, P<.01; and a significant main effect for Shape, F(1,15)=18.31, P<.01.

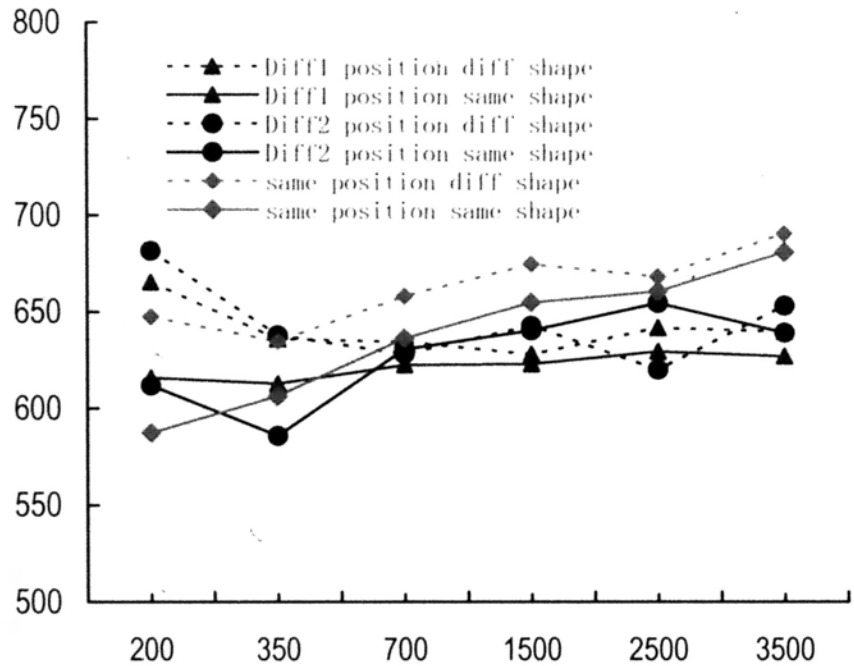


Figure 24: Target detection times, broken down by Shape (repeated, nonrepeated), location (Same, Diff1 and Diff2) and stimulus onset asynchrony (SOA).

As in the color discrimination experiment, there was significant location -based IOR, reflected in the Location x SOA interaction. But again, no attribute-based inhibitory effect appeared. The Shape x SOA interaction indicated there was a difference in the magnitude of RTs for the Shape repetition and non repetition conditions across the SOAs (see Figure 25), but this is not an inhibitory effect. A facilitatory trend appeared early, from the 200 ms SOA through the 700 ms SOA [SOA 200ms, $F(1,15)=22.62$, $P<.01$; SOA 350ms, $F(1,15)=15.26$, $P<.01$; SOA 700ms, $F(1,15)=3.90$, $P=.07$].

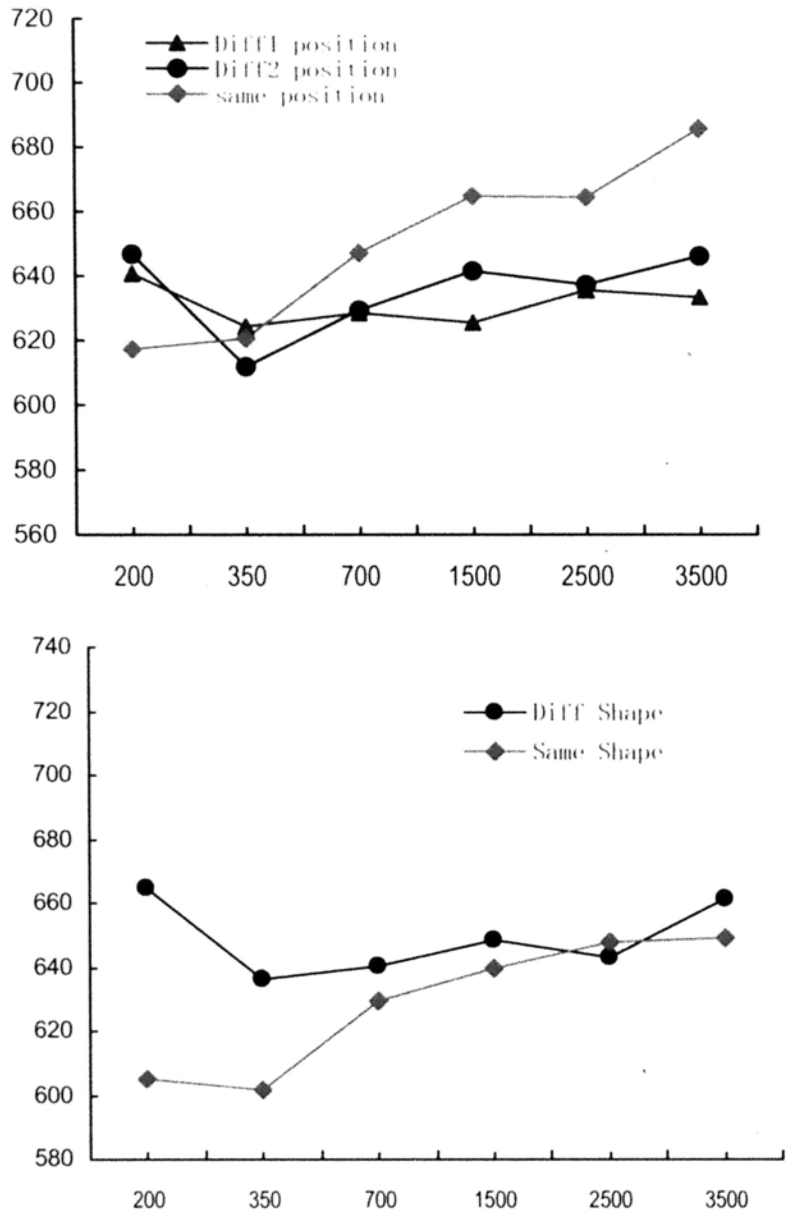


Figure 25. Top panel: figure for the Location x SOA interaction; Bottom panel: figure for the Shape x SOA interaction. X axis: SOA (msec); Y axis: RT(target response times) (msec)

Discussion

In this experiment, using a variation of the Samuel & Weiner (2001) paradigm, we examined shape-based repetition effects in a discrimination task. The results of the present experiment suggest that responding to a shape does not produce an inhibition of return analogous to the inhibition of return that occurred in the shape-based detection experiment. In contrast, location-based IOR appeared in this discrimination task, as it did both in the color-based discrimination experiment and the previous detection experiments.

Experiment 6: Orientation-based repetition effect

Results

Among the 19 subjects, three participants' data were excluded because of higher error rates (more than 10%) or high variance. For the remaining 16 subjects, the miss and error rates were very low, averaging less than 1%. For further analysis, the responses time less than 100 ms or greater than 1500 ms were eliminated as outliers from the analysis.

Mean RTs for each condition are presented in Figure 26. A three-way ANOVA analysis of 2 (Orientation Repetition: repeated vs. nonrepeated) x 6 (SOAs: 200, 350, 700, 1500, 2500 and 3500 ms) x 3 (Location situations: Same, Diff1, and Diff2) was performed. The three-way interaction was not significant [$F(10,150)=1.03$, n.s.]. This finding is similar to previous two discrimination experiments, that is, no orientation-based IOR appeared. As in the previous experiments, we observed a robust location-based IOR (see Figure 27), which was indicated from the Location x SOA interaction effect [$F(10,150)=4.21$, $P<.01$].

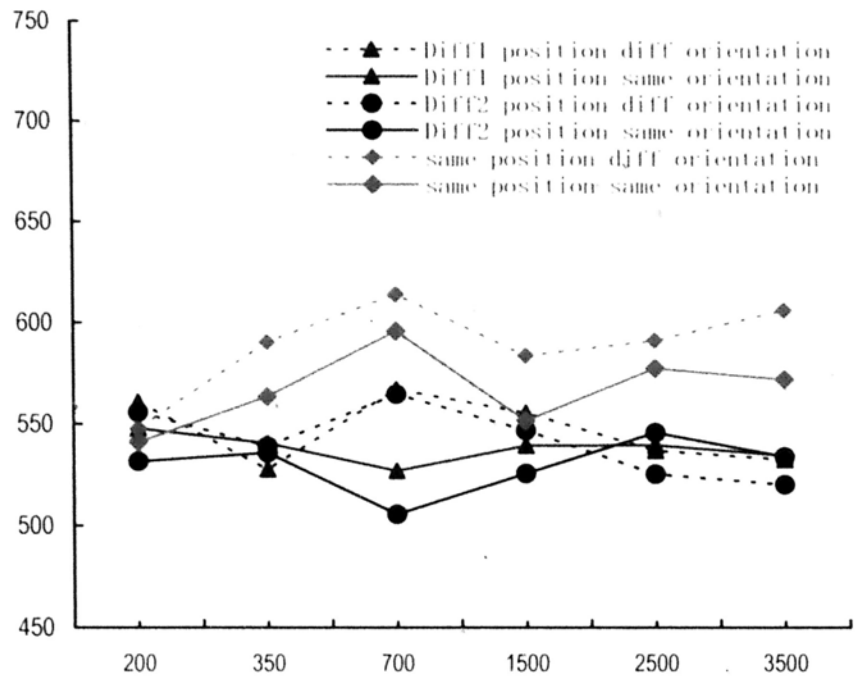


Figure 26: Target detection times, broken down by Shape (repeated, nonrepeated), location (Same, Diff1 and Diff2) and stimulus onset asynchrony (SOA).

The Orientation x SOA interaction was significant [$F(5,75)=2.61, P<.05$], indicating there was a difference in the magnitude of RTs for the Orientation repetition and non repetition conditions across the SOAs (see the Figure 27). The Orientation x Location was not significant [$F(2,30)=1.38$, n.s.]. The main effects of Location and Orientation were significant [Location, $F(2,31)=31.49, P<.01$; Orientation, $F(1,15)=9.32$, $P<.01$]. SOA was not significant [SOA, $F(5,75)=1.28$, n.s.].The general decrease in mean RT for attribute repetition is similar to our previous findings, but this facilitatory effect developed slower and disappeared sooner compared to the results from the color and shape experiments[at SOA 700 ms, $F(1,15)=11.80$, $P<.01$; and at SOA 1500ms, $F(1,15)=6.24$, $P<.05$]. The weaker effect here is consistent with our failure to observe a significant effect of inhibition in the orientation detection task, we suggested that in that experiment that in these displays, the left and right orientations are not distinctive enough to be used very much in encoding, limiting their ability to generate subsequent effects (either facilitation or inhibition).

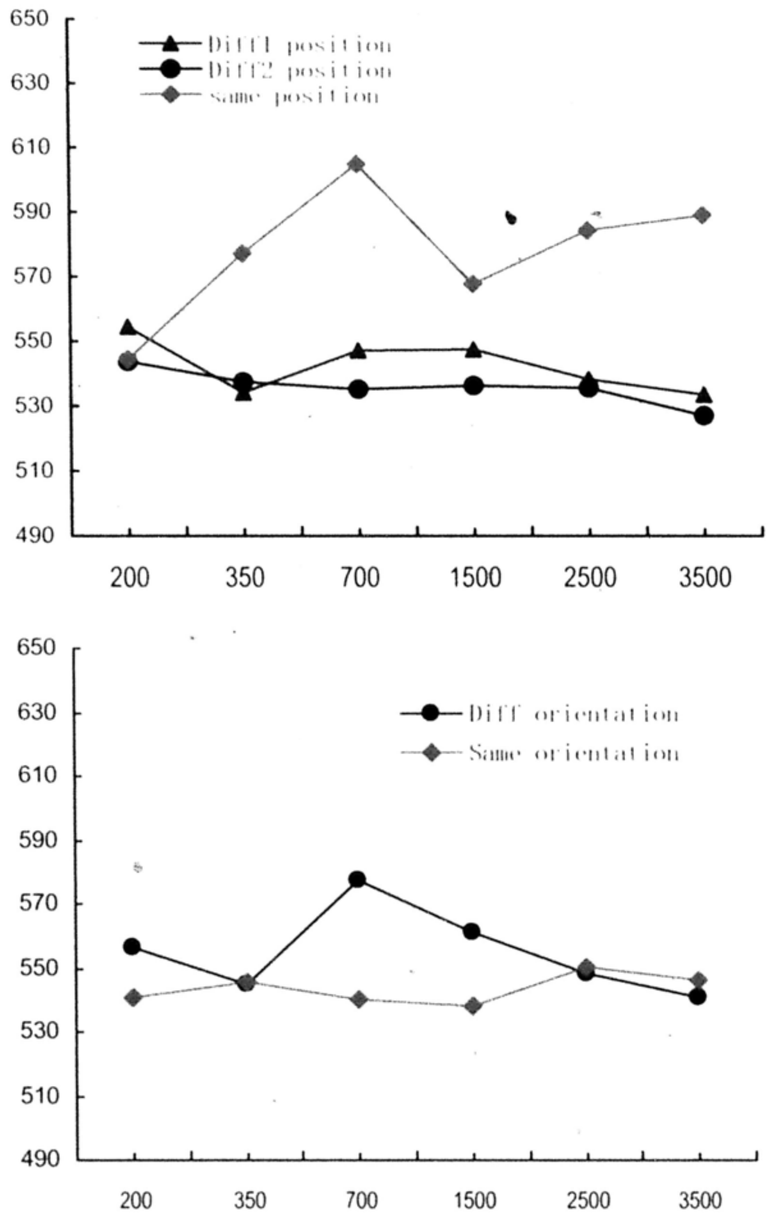


Figure 27. Top panel: figure for the Location x SOA interaction; Bottom panel: figure for the Orientation x SOA interaction. X axis: SOA (msec); Y axis: RT(target response times) (msec)

Discussion

Orientation repetition produced a somewhat weaker facilitatory effect than we found for color or shape repetition. This result complements the pattern found for detection, in which color and shape generated attribute-based IOR, while orientation did not. It is noteworthy that robust location-based IOR appeared in the current discrimination task, in the absence of orientation-mediated effects.

Summary of Experiment 4-6

In Experiment 4-6, we looked for attribute-based repetition effects for color, shape and orientation in discrimination tasks. The results led to this conclusion: there is no evidence of an inhibitory effect based on any one of them. Instead, significant facilitatory effects appeared in this testing situation. Figure 28 summarizes the results from the three experiments described above.

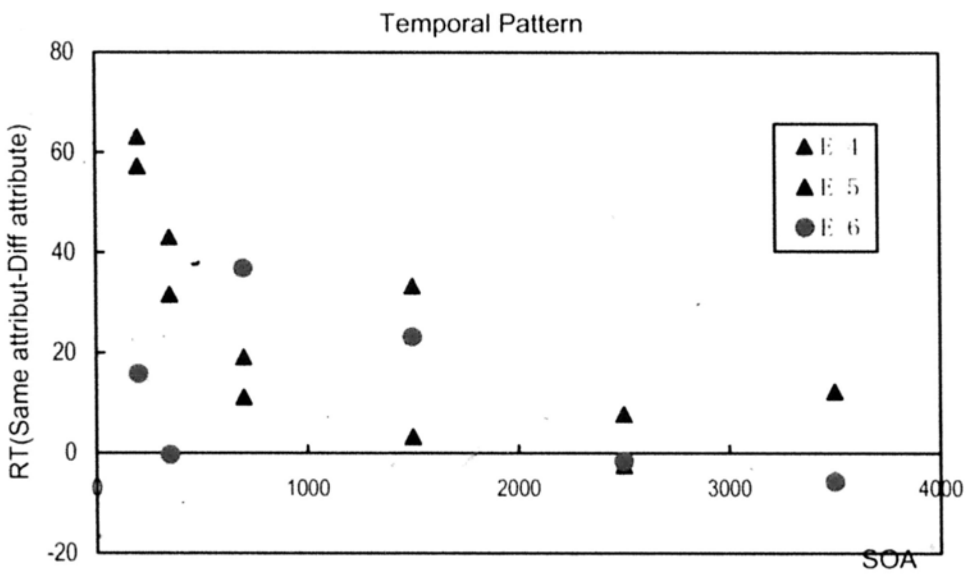
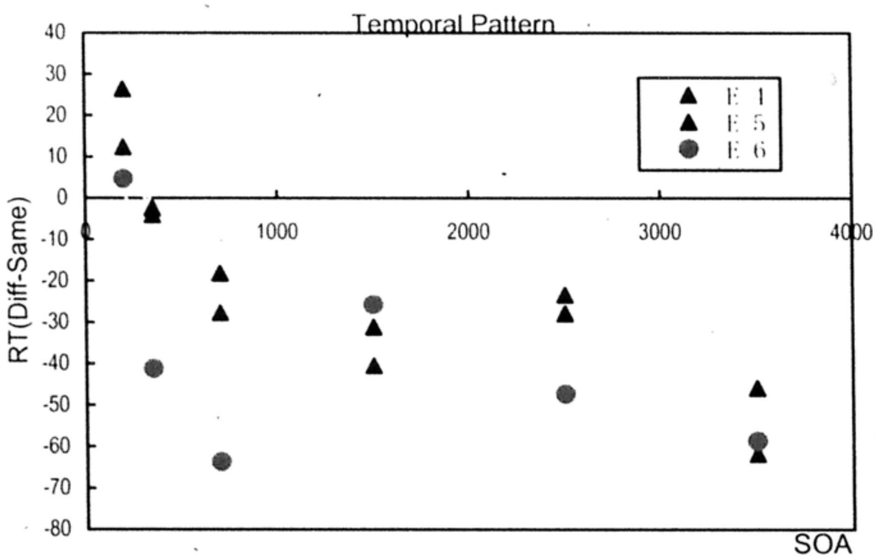


Figure 28: Summary of the attribute-based facilitatory effect from previous experiments. X axis: SOA (msec); Y axis: RT(Diff attribute-Same attribute) (msec). E: Experiment.

For the discrimination tasks used in these experiments, in the demanding visual environment that our complex displays present, no attribute-based IOR was found. We suspect that the high task demands modified the visual processing. The absence of any attribute-base inhibition of effect, coupled with the consistent location-based inhibitory effect in all three experiments (see Figure below 29), suggests that location is much more important in complex demanding tasks. Importantly, for the location-based IOR found in all of our experiments, the temporal properties are consistent with the previous results in the literatures. For the spatial aspect, it is not very clear as that happened in Experiment 1-3.



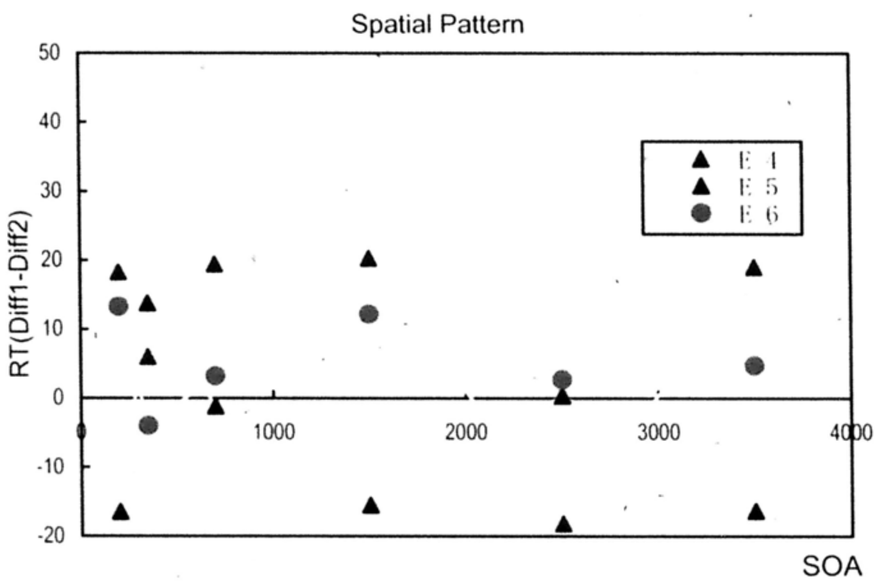


Figure31: Summary of the location-based inhibitory effect from experiments E4,5,6. Top panel: Temporal pattern of the inhibitory effect (Uncued - Cued). Bottom panel: Spatial pattern of the inhibitory effect (Diff1-Diff2). X axis: SOA (msec); Y axis: RT(Diff attribute-Same attribute) (msec). E: Experiment.

Chapter 5: General Discussion

The present set of experiments was designed to address two issues regarding attribute-based IOR. The first issue is whether the nonspatial based IOR effect can be reliably found by using richer displays than have typically been used before. By using Samuel and Weiner's (2001) paradigm, we were able to examine the temporal and spatial factors affecting nonspatial attribute repetition effects directly. Despite some differences among the stimuli used (i.e., whether they varied in color, shape or orientation), there was consistent evidence for attribute-based IOR. Detection experiments with the richer displays produced robust effects, but these effects depended on whether the difference between cue and targets was salient enough. In contrast, for discrimination tasks, the attribute-based IOR was gone, even though these tasks consistently produced location-based IOR (which has been much less reliable in discrimination tasks that have used simpler displays).

The second issue that was addressed was whether the temporal and spatial properties of attribute–based IOR in detection experiments match those of location-based IOR. In the small number of previous studies that examined attribute-based IOR, the observed temporal patterns have been quite variable, and have not matched the established time course of location-based IOR.

In the present discussion, I will relate these results to current nonspatial-based IOR literatures, the role of location and nonspatial attributes in visual processing, the role of the fixation cue in nonspatial-based IOR, the influence of richer displays and the task demands on nonspatial-based IOR, and the temporal and spatial properties of nonspatial-based IOR.

IOR for nonspatial attributes

Over the course of the last twenty five years, investigators have built on Posner and Cohen's (1984) seminal report of a particularly interesting form of attentional selection: inhibition of return. Studies have clarified some basic, defining features of the phenomenon, such as its spatial and temporal properties.

As noted in the introduction, currently, there is debate in the literature as to whether IOR develops for nonspatial attribute searching. Simply put, there are reports that IOR can not be obtained for nonspatial attributes, such as color, shape and orientation (e.g. Kwak & Egeth, 1992; Tanaka & Shimojo, 1996; Terry et al. 1994). In the meanwhile, there are also documented success to observe nonspatial attribute based IOR (e.g. Law et al. 1995; Taylor & Klein, 1998; Fox & de Fockert, 2001). The present experiments were motivated by these mixed results. Here we observed robust nonspatial-based IOR using Samuel and Weiner (2001; Samuel & Kat, 2003)' paradigm. In the experiments (E1a,E1b and E2b), facilitation for nonspatial attribute repetition was found at the shorter SOAs (i.e. before 700 ms SOA); inhibition for nonspatial targets was found at the longer SOAs (since 700 to 3500 ms SOA; the shape-based IOR dissipated earlier than 3500 ms SOA). In other experiments, especially with the discrimination tasks, the nonspatial-based IOR was gone. To explain the implications of our results, we adopted three points for further consideration.

Nonspatial-based IOR: Temporal and spatial properties

As already mentioned, Samuel and Kat (2003) collected the results from dozens of studies that collectively flesh out Posner and Cohen's (1984) original finding of a repetition advantage for about 200 msec, followed by a repetition disadvantage that lasts for approximately three seconds. Several studies (e.g., Bennett & Pratt, 2001; Maylor & Hockey, 1985; Samuel & Weiner, 2001) have delineated the spatial extent of the inhibitory effect.

So far there does not exist a systematic investigation for the temporal and spatial properties of nonspatial-based IOR. The present experiments (E1a, 1b and E2b) demonstrate that nonspatial-based IOR followed a similar time course as location-based IOR, emerging after the 350 ms SOA (if anything, the nonspatial-based IOR may emerge slightly later than the location-based inhibitory effect). And this nonspatial-based disadvantage effect could endure for approximately 3500 ms SOA. Critically, the inhibition observed was much larger than that previous reported. All of these may suggest that the same inhibitory mechanism may underlie both the location-based and nonspatial-based IOR.

Recently, researchers reported that location-based IOR can last up to 13 second following an initial cue in a go no-go task (Wilson et al., 2005)[6]. Although it remains unclear how long nonspatial-based IOR can last (the longest SOA adopted

[6] Tipper and colleagues showed IOR even up to several minutes (Tipper, Grison & Kessler, 2003).

here is 3500 ms SOA), the present results provide solid preliminary evidence that nonspatial attribute-based IOR can exist well up to about 3000 ms.

For the spatial property, the nonspatial-based IOR reported here is only limited in the same condition. It is worthy to note that here in the display of Samuel and Weiner (2001, Samuel & Kat, 2003), the cue and the target events occur within the same circle, but always in slightly different conditions. In contrast, no nonspatial-based IOR appeared in the "Diff1" and "Diff2" conditions. Recall the spatial property of the location inhibitory effect, several studies (e.g. Pratt, Adam, & McAuliffe, 1998; Pratt et al., 1999) suggested that responses became slower (i.e. larger location IOR) as the distance between the cue and target decreased. In a recent article, Bennett and Pratt (2001) reported that slower RTs were observed throughout the cued quadrant, not limited in the cued location, and the magnitude of IOR decreased with the distance from the cued location. It seems it is easy to accept if the nonspatial-based inhibition can spread outward from a cued location[7]. However, we failed to obtain this result in our experiments.

Our results indicated that nonspatial attribute-based IOR does not seem to be independent of location, as it only occurs when the cue and tareget share not only color, but location. Hence the attentional operations for nonspatial attribute are specified in location-based coordinates. One point should be noted, till now, we do not offer a very firm conclusion regarding the spatial map for nonspatial based IOR.

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[7] An insightful but different proposal has been made by Juan Lupiáñez. His theory is that the spatial property of the location inhibitory effect is not comparable to the spatial property of the nonspatial IOR. The comparison would be to see whether we get IOR for exactly the same color (e.g., red), or also for close but different color (e.g., orange). On the other hand, what we see location property of nonspatial IOR would be similar to study the non-location property of location-based IOR. In other words, to see whether we get more or less IOR when other features (color, shape, etc) also repeat or when they are different (pers. commun.).

Why to say this? In Samuel and Weiner (2001)'s paradigm, a target could appear in only a few spatial location conditions (Same, Diff1 and Diff2), hence we suspect the spatial distribution of nonspatial based IOR was sampled some coarsely. Clearly, further work on this aspect is needed.

Nonspatial-based IOR vs. Repetition Blindness (RB)

As noted in the introduction, currently, there is debate in the literature as to whether nonspatial based inhibitory effect belongs to Repetition Blindness. It is true, some researchers (e.g., Fox & de Fockert, 2001; Taylor & Klein, 1998) have argued that the nonspatial-based repetition disadvantage is not really inhibition of return, but is instead a type of repetition blindness.

In a seminal article, Kanwisher (1987, also Kanwisher,1991) introduced a finding which she called "Repetition Blindness"(RB), in which observers fail to detect (or, perhaps, recall) repetitions of items that occur in rapid serial visual presentation. Kanwisher (1987) assumed that there are two distinct forms of visual representation, that is, types (abstract categories) and tokes (specific instance of these categories).To illustrate, a display such as Aa includes two tokens but only one type, in contrast, Ab comprises two types and each type owns one token. In her view, the type coding is not sufficient to reach observer's awareness. By contrast, the token encoding is needed to form an episodic representation of a particular object. Generally, the recognition depends solely on type identification. RB occurs when the interval between repeated two items is too short to ensure a successful token individuation.

Now it is well known that RB is very general and can be observed for letters and pictures, between words and the corresponding pictures or between words in two different languages (see Kanwisher & Potter, 1990, MacKay & Miller, 1994).

Current literature (e.g. Law et al., 1995; Taylor & Klein, 1998; Fox & de Fockert, 2001) provides three issues for the debate between IOR and RB. First, the interval between the repeated stimuli was very short (in Kanwisher, 1991, it is 117 ms). However, in usual IOR experiments, before 300 ms ISI, no IOR appears. Second, establishing an inhibitory effect should depend on an earlier attention capture by the cue. So whether there exists a facilitatory component between inhibitory effect or not is a critical rule to accept IOR explanation or RB view. Third, previous inhibitiory effect observed is just in the condition with a neutral attractor presentation, and this does not support attentional IOR account.

Three accounts of the long dwell times that seem plausible will arguer for a inhibition or return (IOR), rather than repeated blindness (RB) as follows.

First, it is worthy noting that the interval between the repeated stimuli (color) used by Kanwisher (1991) was about 110 ms. It assumes that RB was easier to observe at both longer lags and slower presentations rates. In one experiment, Kanwisher (1987) ever used a presentation rate of 250 ms and 1000 ms SOA between the first and second repeated word and observed the RB with the detestability above 90%. According to the literature, the range of cue-target interval varies from about 100 ms to 1000ms but the strong RB appeared with a 500 ms SOA. It fact, the inhibitiory effect observed in our study is very robust and the effects found for SOAs over two seconds, well beyond the range of repetition blindness. By this account, it is more probable that the long dwell time for the repetition of nonspatial attribute observed in our experiments belongs to IOR, instead of RB.

Second, as we described in the introduction, IOR is often conceived as a biphasic effect (but see Collie, et al., 2000; Pratt et al., 2001; Tassinari et al., 1994, 1998). Law et al. (1995) argued the inhibitory effect observed by them belonged to IOR, instead of RB but they only examine the effect with long SOA (1800 ms). Taylor and Klein (1998) examined simple detection RT to color targets that followed 900 ms color cues by ISIs of 150-900 ms (150, 300, 450, 600, 750, and 900 ms) but failed to show facilitation at early ISIs. Instead, they did find a tendency for the color inhibitory effect at the earliest ISI. So they "argued against requisite attentional orienting to the cue color representation in the first place (P, 1455)" and favored the RB explanation. In fact, with rich display paradigm of Samuel and Weiner (2001), we did observe facilitation effect in the shorter SOAs (e.g. 200 and 350 ms SOA), followed by inhibition effect in the longer SOAs (e.g. 700, 1500 and 2500 ms). Evidence comes from Experiment 1a (without neutral attractor, also Experiment 2b) and 1b (with neutral attractor). It seems this belongs to a methodological issue, but not because the inhibition effect belongs to the RB effect.

Third, as we have mentioned above, previous facilitation effect is only observed in the condition with a neutral attractor presentation, hence it does not support attentional IOR account. It is possible that the neutral attractor may be serving as a kind of separator that contributes to a form of repetition blindness. However, in the present Experiment 1a and Experiment 2b, robust color- and shape-based IOR clearly appeared since 700 ms SOA. So this goes well with the attetional IOR account. In addition, Kanwisher has shown that RBs are most likely at relatively short lags between the first and second presentation of an item (see Luo & Caramazza, 1996, for an examination of the time course), but that some separation enhances the effect; the neutral attractor might serve this function under some testing conditions. For the complex displays used in the current study, the irrelevance of the attractor was inserted, but the nonspatial-based IOR did not change significantly. So this is additional evidence that the effects observed here, at least those observed in the detection task, are likely to be true inhibition of return, rather than a variant of repetition blindness.

In addition, although a number of researchers found impaired performance for targets that had been preceded by stimuli sharing attributes like color (e.g., Fox & de Fockert, 2001; Law et al., 1995; Taylor & Klein, 1998) and shape (e.g., Fox & de Fockert, 2001; Riggio et al., 2004), the size of the impairment was much smaller than typical location-based IOR. Most reported that impairment was 5-6 ms, but ours are lager than this; some are almost 20 ms or above, which are more like that happened in the location-based IOR experiment. So this encourages us to believe ours belongs to nonspatial-based IOR, instead of other effect. Consistently, Samuel and Weiner (2001), and Samuel and Kat (2003) also found that with their setting, more complex than those used in most IOR studies, the effects were about twice as large as those found with more typical displays. As to the magnitude issue, we will discuss its effect below.

To conclude, we report here a robust inhibitory effect, and support that nonspatial-based IOR reflects less than perfect token individuation as suggested by Kanwisher (1987).

Location vs. Nonspatial attributes

As discussed above, the data from the present study does reveal several interesting results. It seems our results are useful to help to understand the debate of whether the location is special or nonspecial.

Over the last few decades, there has been considerable debate over the relative importance of location-based versus feature-based visual attention. Some argue that location is just one type of feature, similar to color, shape and orientation (e.g. Bundesen, 1990; Laarni, 1999; Laarni et al., 1996), whereas others propose that stimulus selection via spatial location is primary (e.g., Schneider, 1995; Tsal & Lavie, 1988; 1993; van der Heijden, 1993). Importantly, these different results have led to very different theories about how attention is covertly oriented to location and features.

Does spatial location really enjoy the privileged status that was assumed, or should location be considered just another attribute of each object, along with its size, shape, color, etc.? This perspective led to a small number of studies that looked for IOR that was assigned on the basis of attributes like color and shape, rather than on the basis of location. As we discussed in the introduction, these studies have not produced any clear answer. The fact that our experiments produced robust IOR for a feature (color, and shape), with a similar time course to IOR for location, might be taken as support for the view that location is just another type of feature (e.g. Bundesen, 1990; Laarni, 1999; Laarni et al., 1996). However, we only observed color-, and shape-based IOR in the "Same" condition – there was no systematic evidence for an inhibitory effect at either Diff1 or Diff2. Thus, the most reasonable interpretation of the present results is that attentional operation can be applied to stimulus properties, but in the mean time, it entails directing attention to its location. It seems that IOR accrues at both the initially cued attribute, and the place/location occupied by the cued attribute before attention was drawn away. Therefore, we suspect that the selective processing of nonspatial attributes is still a locational phenomenon.

From another perspective, location is not solely a sensory attribute in the way that nonspatial attribute is. According to Barry (2006) and Dukewich (2009), space (location) is an attribute of both the stimulus and the orienting response. Of special interests to this suggestion is a finding that the location of the cue is a sensory attribute, as is the color, but in the meanwhile, the motor component of the orienting reflex is also location-based. So we speculate the reason that we do not obtain the nonspatial IOR in the Diff1 and Diff2 condition is, in all likelihood, the reflexive motor response effects were not integrated. Consistent with this view, Tsal and Lavie (1988, 1993) pointed out that nonspatial attributes of a stimulus including color are more likely to be attended if attention is directed to the location of the stimulus. This view of feature representation is consistent with classic theories of visual search, including both Feature Integration Theory (Treisman & Gelade, 1980) and Guided Search (Wolfe, Cave, & Franzel, 1989), as these theories argue for feature "maps" that are spatially represented.

In the present study, the color- and shape-based IOR demonstrated, and only demonstrated when the cue and target shared the same location. We suggest that this surprising pattern stems from the nature of feature- and object-based representations and probably, the nonspatial IOR is rather object based[*]. It is easy to see that when the cue and target do not share location, they can not be the same object. Supporting this conclusion is what Kahneman et al. (1992) proposed: for further easily and better analysis, targets appearing in close spatial-temporal proximity might be integrated within the same object file. Lupiáñez (2009) also used this approach to explain his "Spatial selection" theory. Similarly, Hommel (2004) introduced a "partial match costs" term to suggest that repeating some but not all the features of an event produces worse performance.

Recently, McAuliffe, Pratt and O'Donnell (2001) suggested that IOR is a unitary phenomenon and IOR does not consist of separate components like location-based and object-based ones. Their speculation is that under some situations objects will be more effectively attended to and this will result in greater IOR. Generally, it is accepted that IOR exists in both the attentional and the oculomotor

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[*] Juan Lupiáñez offered this very important piece that the data means that feature IOR is rather object based. When the cue and target do not share location they can not be the same object (pers. commun.).

systems, attenional IOR inhibits both cued locations and objects while oculomotor IOR works for eye movements to cued locations. Actually, in our experiments, the nonspatial IOR appears robust too. As we have discussed above, it is reasonable to assume nonspaital IOR is object-based, that is to say, location-based, nonspatial-based and object-based IOR stands for a unitary covert orienting phenomenon - this is a framework to understanding exogenous cueing effects in general.

Important factors for nonspatial attribute-based IOR

There are a number of factors that may influence the development of nonspatial attribute-based IOR. Typically, the key factors talked about in this thesis are as the featural difference between the target and attractor, the complex level of the stimulus display, and the task required for the task.

The featural difference between the target and attractor

Is nonspatial attribute-based IOR blind to features? Our findings suggest that the visual system is indeed sensitive to the featureal difference at inhibited locations[9].

Recall we sought to investigate the nonspatial attribute-based IOR in sets of experiments. Though with the similar experimental procedure, also similar task requirement, attribute-based IOR only appeared in Experiment 1a, 1b and Experiment 2b. It is easy to accept that colors like red and blue, shapes like filled circle and open square offer salient feature difference for the perceptual encoding. By contrast, if the difference between target and attractor is not salient enough, like the stimuli used

[9] Since the nonspatial-based IOR only was observed in the "Same" condition, here we only discussed the facilitation and inhibition in this situation.

in our experiments (both filled circle and square, left and right 45 degree orientation lines), inhibition were very small or inverted to facilitation to detect targets appearing at the initially cued attribute. The findings are summarized schematically in Figure 20, and clearly they are in general consistent with our assumptions.

Thus it seemed to be clear that the featural difference leads to a kind of repetition effect dissociation: salient difference of the stimuli leads to nonsspatial attribute-based IOR, while with less salient difference, IOR is gone. One reasonable interpretation is that the feature difference is a critical factor in inducing nonspatial attribute-based IOR. It is plausible to regard it (feature difference weighting) as a search strategy adopted by the observers. Hence it means IOR is a bottom up cue-awareness assessment and the mean response time to nonspatial attributes is clearly environmentally based.

In fact, the same way there seems to be a spatial gradient in location-based IOR (the maximum being at the same location, but the effect being observed also at near locations), a similar gradient might be observed at other features. Thus for the effect to be observed, cue and target needs to be very different, the same way for the spatial IOR effect to be observed cue and target must be presented at different location (the more different, the bigger the effect)[10].

We have demonstrated that a relatively simple pre-attentive nonspatial processing scheme, based on the difference of the target and distractor. It also seems plausible, IOR acts as a memory for this. According to Itti and Koch (2001) and Klein

[10] Juan Lupiáñez offered this comment (pers. commun.).

(1988), IOR has been assumed to be a crucial mechanism of attentional orienting in that it bias the attention from permanently focusing on the most salient stimulus. So our results supported this view, the preattentive processing involves a saliency coding. It is easily to further speculate that two visual processing may happen in the visual searching: first, a bottom-up and fast primitive mechanism biases the observer towards selecting stimuli based on the saliency and the most salient attributes will be visited by the visual attention with higher probability, then next goes in the order of decreasing saliency; the second inhibition, a top-down mechanism with variable selection criteria initiates.

For the location-based IOR, we assume the possibility that because the location (a special feature) is extremely salient, so usually location-base IOR has been easier to observe.

The influence of rich display on nonspatial based IOR

As we have reviewed in the introduction: preceding work was performed usually with a very simple display. Posner & Cohen (1984)'s cue-target paradigm is the typical one, that is, the display only presents us one or two potential items worthy of attention. Definitely, this method has led great success in the location-based IOR research area. Now this visual search paradigm has been used extensively. As noted earlier, there were some hints in the attribute-based studies that an inhibitory effect might be most detectable when the stimulus situation was relatively complex, with more evidence of inhibition with displays that had more probed locations (e.g., Kwak

& Egeth's (1992) four-location test), or more dynamic properties (e.g., the insertion of an "attractor" between the cue and target events, Law et al., 1995). There were also hints that if this inhibitory effect occurred, it might be limited in spatial extent to regions near the cue event (e.g., Kwak & Egeth, 1992; Riggio et al., 2004).

We believe that a more ecological situation in spatial and nonspatial inhibitory effect research area is underappreciated in the past years. Actually, as we have described in the story above, researchers now begin to consider the experimental paradigm problems. Now, a number of more complex models have been proposed to address some difficulties of a strictly serial model (e.g., Nakayama & Silverman, 1986; Samuel & Kat, 2001; Samuel & Weiner, 2003; Wolfe et al., 1989).

In fact, Samuel and colleagues adopted a richer display and observed that the phenomenon of the location-based IOR is robust. Their paradigm included many locations (eight circular regions), with a relatively high number of small figures in the displays, each with relatively high positional uncertainty. In addition, in this paradigm, the cue (the first small figure added to the initial display) is not removed when the target appears, because the cue and target do not spatially overlap, even in the "Same" condition. Tassinari et al. (1994) have argued that this arrangement strengthens inhibition of return, because the non-informative cue remains visible during target processing (for a similar view, see Takeda & Yagi's (2000) work on "inhibitory tagging").

In our experiments, the observed inhibition was both larger than the effects previously reported, and critically, it followed a similar time course as location-based

IOR, emerging after the 350 msec SOA (if anything, the color-based effect may emerge slightly later than the location-based effect, a clear divergence from the repetition blindness-like pattern in earlier studies). The results of Experiment 1b provided a clear replication of Experiment 1a's findings. Similar results are reached in experiment 2b. It seems such a richer display is one of the hallmarks to initiate nonspatial-based IOR. Critical insight to this result invites a speculation that it is better to take a moderate complex display to research the nonspatial-based inhibitory effect.

For the influence of rich displays, there happened an interesting story in the IOR research history. Klein (1988) published a paper named "Inhibitory tagging system facilitates visual search", demonstrating that IOR can operate in serial search task hence improves search efficiency. Unfortunately, following this research are several nonreplications reporting. Among them is a paper from Wolfe and Pokorny (1990). In the year of 1994, Klein had to admit no studies had replicated the original findings and wrote "these nonreplications from the Klein laboratory, together with those from other laboratories, was the product of chance (alas fluke)" (Klein & Taylor, 1994, p138). But almost six years later, researchers found that the paradigms adopted by them were not appropriate for testing because the items were removed from the display. If the items were maintained, inhibitory tagging could be observed (Muller & von Muhlenen, 2000; Takeda & Yagi, 2000). The story offers evidence that IOR effect only appears in an attentionally demanding search condition and the IOR was gone when the search objects were removed after the search-task response.

In simple detection experiments, we obtained robust nonspatial attribute-based IOR; however, in the experiments of Chapter 4, we did not obtain any nonspatial attribute–based IOR. Why we observed the nonspatial attribute-based IOR? Where has the attribute-based IOR gone in the discrimination tasks?

As mentioned in the introduction, Lupianez et al. (1997) demonstrated that inhibition can occurs in discrimination tasks. In their experiments, the participants were required to respond based on the color of the target. The effect of inhibition occurred but began at a later SOA and ended at an earlier SOA, in comparison with the inhibition in simple detection tasks. Lupianez and colleagues pointed that the onset of IOR was related to the complexity of the task required in the experiments (Lupianez & Milliken, 1999; Lupianez et al., 2001).

Firstly, we consider the top-down issue. According to Klein (2000), it seems that observers adopt attentional control settings for the task. For the higher demanding, hence difficult tasks, the setting leads to the delayed onset of IOR, even leads to the disappearance of IOR (of course, this remains a debate, see the discussion on the biphasic process). With an easy task, usually a simple detection task, the attentional setting is prepared in a low level and the cue is weakly attended. This setting helps for the attention quickly disengagement from the cued location/attribute, therefore it helps to the early development of IOR. This theory assumes a difficult or slow disengagement of attention from the cued locaition/attribute in the difficult tasks. For the data in our discrimination tasks, the work load damages the attention disengagement processing in the nonspatial attribute, hence the nonspatial attribute-based IOR is gone. By contrast, in the same detection tasks, we clearly obtained roubust nonspatial-attribute based IOR.

Secondly, the bottom-up issue is considered. Actually, our data indicate that if the target is harder to perceive or not salient enough, the results will be happened like that in our Experiment 2a and Experiment 3. As noted earlier, the target salience affects the development of nonspatial attribute-based IOR. In both of the Experiment 2a and Experiment 3, we only observed a weak nonspatial attribute-based IOR. Actually, the high salience of the target, more usually, decreases the task demanding. In all, both of them support the task demanding suggestion.

How to explain the relationship between the richer display and the task difficulty? It is true that richer display and task difficulty are far from irrelevant. In our view, the adoption of the richer display aims to letting the experiment owns an ecological situation. And our cognitive processing is involved within the complex environment—this is a biological perspective. By contrast, the task difficulty much more greatly affects the allocation of attention.

As Lupiáñez suggested (pers. commun.), the IOR effect that is measured is always a mixture of the contribution of different mechanism: detection cost, spatial benefit (regarding location). The same could be applied to other features: color detection, color categorization, color-response selection, etc. In discrimination tasks, the contribution of the mechanisms different from detection cost is increased. This contribution is further increased in discrimination tasks for feature-based IOR. Note that when the same color repeat in a discrimination task, not only the attribute repeats (as location in a detection task), its category, its appropriate response, etc also repeat. This explains why we only observed facilitation instead in the discrimination experiments. The facilitation would have been even higher if a target-target procedure had been used (as did Tanaka & Shimojo, 1996), because with that procedure, when the same target repeats we get a great benefit by retrieving the previous episode with the target already categorized, and its appropriate response already selected. Another perspective is discussed below.

Another explanation is suggested by Tanaka and Shimojo (1996). Since our results clearly demonstrate dissociation between two tasks, they encourage us to consider that there exist two independent visual biological mechanisms: one for location and nonspatial attributes' detection task (less demanding) and the other for features' discrimination (higher demanding). Tanaka and Shimojo (1996) and Shimojo et al. (1996) did proposed a "where" vs "what" or "action" vs " recognition" pathways for the location and feature analysis tasks. It seems plausible to assume that feature discrimination needs higher mental work and more awareness hence it works in an analysis pathway. So, maybe the high task demands invoked the different visual processing mechanisms. The absence of any nonspatial attribute-base inhibition of effect, coupled with the consistent location-based inhibitory effect in all three experiments, suggests that location mechanism is initiated for the detection tasks. It would be more efficient if the first location mechanism is the lower one and usually runs firstly. So we can always easily find the location-based IOR.

Unfortunately, we need to admit, so far no direct study has been done on the relationship between them. The proposition presented here, clearly, might be further substantiated, explained, challenged even modified.

Other factors on nonspatial attribute-based IOR

Though we have discussed some key factors which may affect our experimental results, there are still some factors have been shown to be influential in modifying the allocation of attention to facilitate visual searching.

One is the neutral attractor. As stated earlier, Law et al. (1995) had introduced the attractor in the much simpler displays used in most of the previous attribute-based IOR studies, and both their findings and those of Taylor and Klein (1998) demonstrate a significant effect of removing attention from the cue. Definitely, the paradigm employed by them belongs to a central display one, the stimuli all were presented in the central position of the display. Further studies, though began to focus on the spatial-based IOR, adopted the moderate display, together with the exogenous reorienting cuing. Typical arrangement is that after a peripheral cuing is presented with certain time, an exogenous cue is used to reorient attention before the appearance of the target. but the results are mixed. For example, Pratt, O'Donnell and Morgan (2000) examined the role of the neutral attractor and reported that reorienting attention to a fixation location results in a significant reduction in the inhibitory effect. Pratt (2002) proposed that the fixation cue plays a role in experimental studies of IOR, but only at shorter SOAs, He assumed that only there is a brief period of time in which observer can not withdrawn his/her attention from the peripherally cued location. Given the robust effects observed in our Experiments 1a, 1b and 2b, this may prove to be of more methodological than theoretical importance. Specifically, the similarity of the results of Experiment 1a, 1b argues against any critical role for the attractor in these more complex displays for nonspatial attribute-based IOR. So the neutral attractor has not much influence in detection tasks. However, it is reasonable to propose that it has a great effect in discrimination tasks. The chances to observe feature-based IOR in the discrimination tasks might be much greater if a neutral attractor is adopted. What the neutral attractor makes is to close the representation of the cue so that we are slowed to detect it again when the target is similar or same to it (this is from Lupiáñez, pers. commun.). This is a future research issue.

According to Cheal (1997), though may be with moderate effect, many other factors should be considered carefully for the nonspatial attribute experiments. For example, the experimental instructions (e.g. Gottlob et al., 1999) and the size of the cue and target (e.g. Lambert & Sumick, 1996) more or less would affect the results.

Concluding remarks

To summarize, the present thesis demonstrates (a) the disadvantage repetition effect of the nonspatial attribute observed belongs to IOR, instead of repetition effect; (b) this nonspatial attribute-based IOR can be demonstrated in moderate complex displays if the stimulus salience is sufficient, but this effect does require a neutral attractor inserting; (c) it follows a time course similar to that for location-based IOR and; (d) nonspatial attribute-based IOR does not generalize to discrimination tasks.

The present research clearly demonstrated nonspatial attribute-based IOR and examined the requirements for its development. As Posner said, "the goal of every science is a cumulative development of its theoretical structure so that a larger part of its subject matter is explicable in terms of simpler principles (Posner, 1982, p168) ", our study just opens a way to deepening our understanding of the nonspatial-based repetition effect.

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