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J Exp Psychol Gen. Author manuscript; available in PMC 2012 February 1.

Published in final edited form as:
J Exp Psychol Gen. 2011 February ; 140(1): 35–50. doi:10.1037/a0021091.

Eliminating Inhibition of Return by Changing Salient Non-spatial Attributes in a Complex Environment

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Abstract

Inhibition of Return (IOR) occurs when a target is preceded by an irrelevant stimulus (cue) at the same location: Target detection is slowed, relative to uncued locations. In the present study, we used relatively complex displays to examine the effect of repetition of nonspatial attributes. For both color and shape, attribute repetition produced a robust inhibitory effect that followed a time course similar to that for location-based IOR. However, the effect only occurred when the target shared both the feature (i.e., color or shape) and location with the cue; this constraint implicates a primary role for location. The data are consistent with the idea that the system integrates consecutive stimuli into a single object file when attributes repeat, hindering detection of the second stimulus. The results are also consistent with an interpretation of IOR as a form of habituation, with greater habituation occurring with increasing featural overlap of a repeated stimulus. Critically, both of these interpretations bring the IOR effect within more general approaches to attention and perception, rather than requiring a specialized process with a limited function. In this view, there is no process specifically designed to inhibit return, suggesting that "IOR" may be the wrong framing of inhibitory repetition effects. Instead, we suggest that repetition of stimulus properties can interfere with the ability to focus attention on the aspects of a complex display that are needed to detect the occurrence of the target stimulus; this is a failure of activation, not an inhibition of processing.

Keywords

Inhibition of Return; Non-spatial attributes; Location; Habituation; Object-file

Over the course of the last three decades, there has been a great deal of research examining aspects of visual search, clarifying how people parse the potentially overwhelming amount of visual information that is constantly available. Among the many paradigms used to investigate visual attention and selection, the spatial cuing paradigm developed by Posner (1980) has been instrumental in revealing important aspects of attentional allocation. In a

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seminal paper, Posner and Cohen (1984) demonstrated that people are slower to detect targets in recently cued locations than in novel locations. In their experiments, three boxes were presented on a screen, one at the center, with the other two located on either side of the central box. A trial began by brightening one of the peripheral boxes for 150 ms (the “cue”). The task was to detect a small dot (the “target”) in the center of one of the boxes; targets appeared 0–500 ms following the onset of the cue. The target appeared at the central box with a probability of 0.6, at each of the peripheral boxes with probability 0.1, and not at all (catch trials) with a probability of 0.2. Posner and Cohen found that when targets quickly followed cues detection was facilitated, but when the stimulus onset asynchrony (SOA) was greater than 300 ms, people reacted more slowly to targets at previously cued locations than at uncued locations. Posner, Rafal, Choate, and Vaughan (1985) termed this inhibitory effect “inhibition of return” (IOR) (for a review, see Klein, 2000). This term was chosen to indicate that attention was “inhibited from returning” to previously inspected locations.

In the years following Posner and Cohen’s (1984) discovery of IOR, the inhibitory phenomenon has been widely investigated. A common suggestion (e.g., Klein & MacInnes, 1999) has been that by biasing the visual system against reorienting towards a previously examined visual location, IOR enhances the likelihood of searching novel locations. Studies have clarified some basic, defining features of the phenomenon, such as its spatial and temporal properties. 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. 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; 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. Lupiáñez et al., 1997; Pratt, 1995; 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, 1991; Tipper et al, 1994).

Tipper et al. (1991) were the first to report that processing is inhibited from returning to previously inspected objects. 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. Given the spatial (i.e., retinotopic) organization found at multiple levels of the visual system, this kind of system seems relatively straightforward. However, 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 simply in the default parameter space of the visual system. This opens up the possibility that inhibition can be associated with non-spatial 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.

Cast in broader terms, a fundamental issue is whether location is qualitatively different than other features (see Tsal & Lavie, 1988, 1993). In fact, most theorists do see a special role for location, relative to other properties. Kubovy (1981) has articulated this position most forcefully, calling location the “indispensable attribute” for vision. The primacy of location

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can be seen in classic models of search (e.g., Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989), in which objects are specified by collections of features that co-occur in internal “maps” that are spatially organized. Currently, a descendent of these models -- object file theory (e.g, Kahneman, Treisman, & Gibbs, 1992) places location in both the role of a feature and the role of an "indispensable attribute". In object file theory, object files are episodic representations of objects in the surrounding environment which contain current information about the description (visual properties) and location of the objects; in that sense, location is just another feature. However, object files are addressed through their spatial locations, making location a dominant feature. For our current purpose, the central issue is whether inhibition of return is a strictly spatial phenomenon. As we review below, the evidence in the literature that inhibition of return applies to non-spatial attributes (e.g., color, shape) is extremely weak. And, as we argue in the General Discussion, the domain over which the inhibitory effect operates provides important constraints on the extent to which it makes sense to invoke a specialized process that specifically inhibits returning attention to a previously attended stimulus.

We should note that our focus is on “classic” inhibition of return, which involves slower detection of targets that are displayed in a previously cued location (Posner & Cohen, 1984). There are many other excellent studies related to this effect that rely on discrimination tests (e.g., Lupiáñez et al., 1997), or even tests in another modality, such as audition (e.g., Mondor et al. 1998; Mondor & Lacy, 2001). Our research strategy is to first try to obtain a stable pattern in one well-defined domain, and then carefully extend the theory to related domains. The most-studied domain in this research area has been stimulus detection. Moreover, even in accounts of repetition costs on discrimination tasks, the inhibitory effect is often attributed to detecting the stimulus needed to make the discrimination (e.g., Lupiáñez, 2009). As such, in the present study, we focus on inhibitory effects on detection. In follow-up work, we examine complementary cases using a discrimination task (Hu & Samuel, 2010).

Non-spatial Inhibition of Return

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 for a previously cued location. However, there have been a small number of studies that have looked for inhibition based on other features, such as shape, color, or orientation. Of these small literatures, the largest concerns color-based inhibition of return: Is it more difficult to detect a target of a particular color, if a stimulus of the same color was recently the focus of attention? As we review this literature (and the even smaller literature on shape-based inhibitory effects), it will become apparent that the answer to this question is currently unclear, with very mixed results regarding the existence of attribute-based IOR. In Experiments 2 – 5, we will report results that we believe offer a clearer answer than is currently available. These results suggest that some of the confusion in the literature may stem from a poor conceptualization of the inhibitory effect.

Kwak and Egeth (1992) were the first to look for color-based IOR. They reported a set of experiments using a continuous-responding paradigm. In this paradigm, subjects perform 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; this approach is sometimes called a “target-target” method, in contrast to the “cue-target” procedure that uses cues that do not call for a subject response. Across experiments, Kwak and Egeth varied the number (one, two, or four) 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

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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 5-ms color-based inhibitory effect in one experiment, 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 a similar 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 Francis & Milliken, 2003; and 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 before its return can be inhibited. 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 ms 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 ms 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 ms SOA that Law et al. had used, Taylor and Klein tested ISIs of 150, 300, 450, 600, and 750 ms, 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 ms (Samuel & Kat, 2003). From this perspective, there should have been no inhibitory effect for the 150 ms ISI 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 ms for the conditions with the attractor, regardless of SOA, and no significant 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 time course 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

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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 ms range, but the magnitude of the effect tended to decline as the SOA was increased from 200 to 900 ms. 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 Umiltà (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 ms at fixation, and about 10 ms 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 attribute-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 color or shape 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. The most robust color-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 ms range, whereas the typical IOR effect in the literature is about 25 ms (Samuel & Kat, 2003); in many of the studies finding small attribute-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 color-based effect is more likely to be some kind of repetition blindness, rather than inhibition of return (but recall that Riggio et al, 2004, did not find the phonological pattern typical of repetition blindness).

There are some hints in the existing attribute-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 cue, to the attractor, to the target. In addition, the condition in Kwak and Egeth's (1992) original study that produced an inhibitory trend was one that presented stimuli at four different possible locations (and all of the other studies in this literature were limited to one or two locations).

The Present Research

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. These were

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designed to allow many possible manipulations, while still keeping very tight experimental control. Samuel and Kat (2003) found that this methodology was effective in delineating the spatial and temporal properties of IOR. Moreover, the IOR effects using the relatively complex displays were generally about twice as big as those found with simpler displays, which may make this paradigm well-suited to look for attribute-based IOR effects that have been vanishingly small in studies using simple displays. In a typical experiment using Samuel and Weiner's paradigm, the display has eight medium-sized gray circles arranged in an imaginary circle around fixation. In each of the gray circles, there are 0, 1 or 2 smaller figures. In the two published studies using this paradigm, four types of small figures were used: red circles, blue circles, red squares, and blue squares. These choices can be adapted to the needs of the particular questions being studied, including those involving attribute-based effects. Because the experiments in the current study use this methodology, we will describe it here.

A typical trial sequence, consisting of four sequential frames, is illustrated in Figure 1 (bottom). First, a frame with a white fixation cross (1°) appears on a dark gray background for 250 ms. The second frame (750 ms) includes eight light gray circles (diameter = 3.7°), arrayed in a circular fashion around the fixation cross (radius=6.8°). Four empty circles alternate with four filled circles, each of which contains two small (1°) figures. In Frame 3, as a cue event, a new small figure appears (red or blue, square or circle) 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 square or circle is presented; the color and shape of the target is randomly selected each time. The target occurs equally often in four locations: the same gray circle as the cue ("Same" condition), 90° away -- clockwise, 90° away -- counterclockwise (the 90° locations together comprise the "Diff1" condition), or 180° away ("Diff2" condition).[1] 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 (for related discussion, see Wang & Klein, 2010). 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; as noted, the reaction time costs for the Same case were generally 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 Experiment 1 below).

The central aim of the present study is to look for feature-based effects of exogenous cueing using these richer displays. As noted above, a simple detection task is used in all of the experiments. If an inhibitory effect is found, an additional aim is to determine whether the spatial and temporal properties of the effect are comparable to those for location-based IOR. Thus, in Section 1 (Experiment 1) we first provide a set of data that establishes these spatial and temporal properties of location-based IOR for our equipment, software, and subject population. Section 2 includes two experiments, examining whether a color-based inhibitory

[1]In Experiment 1 of the current study, we followed the procedure used by Samuel and Weiner (2001) in the implementation of the Target Location factor: Targets were equally likely to be presented at four locations (Same, Diff1 [clockwise], Diff1 [counterclockwise], and Diff2). Note that although this yields targets equally often at each physical location, it includes twice as many Diff1 targets as either Same or Diff2. We used this procedure to exactly match what Samuel and Weiner had done. In Experiments 2–5, we used the slightly modified procedure that Samuel and Kat (2003) employed: Targets were equally likely at Same, Diff1, and Diff2, with half of the Diff1 trials being clockwise, and half counterclockwise, relative to the cue. Samuel and Kat used this approach to reduce the number of trials needed in their factorial design, and we did the same here. A post hoc analysis confirmed that there were no differences between clockwise and counterclockwise trials. Nevertheless, researchers need to consider these two alternatives carefully for certain situations, as one approach balances the number of targets a certain distance away from the cue, while the other approach balances the probability of occurrence of a target at a given location. At least in theory, by splitting the Diff1 targets as we did in Experiments 2–5, these locations are at a disadvantage compared to the more frequent Same and Diff2 target locations. There were no predictions in Experiments 2–5 that depended on this factor, making the issue moot here, but in some cases it could matter.

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effect occurs in this paradigm, and if so, whether its spatial and temporal properties are similar to those in the location-based Experiment 1. Experiment 2 directly tests this issue, and given the conflicting results in the existing literature, Experiment 3 tests whether a neutral attractor affects the pattern of effects in these more complex displays. Section 3 also includes two experiments (Experiments 4 and 5), both of which use a different non-spatial attribute than in Section 2. Across these two experiments, we manipulate the salience of target-distractor differences, to see whether the inhibitory repetition effect varies as a function of the distinctiveness of the cues and targets. The distinctiveness manipulation can help to choose between the traditional facilitation+inhibition account of IOR and two alternative views that treat inhibitory effects as a consequence of more general processes of habituation (Dukewich, 2009) or object identification (Lupiáñez, 2009). To foreshadow, the results of our experiments are more compatible with an account in which these more general perceptual principles account for the inhibitory effects than with the more standard view that there is a process that is specifically designed to force attention away from a recently attended location (or object).

Section 1: Establishing the Pattern for Location-Based IOR

Experiment 1

The first experiment has two goals. The first goal is to replicate the basic paradigm, since all of the published results from this task have come from a single laboratory (Samuel & Kat, 2003; Samuel & Weiner, 2001). Experiment 1 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). The second goal is to provide a benchmark for the temporal and spatial properties of location-based IOR under the current testing condition, which can be compared to the patterns found in Section 2 (color-based repetition) and Section 3 (shape-based repetition). The testing conditions of Experiment 1 integrate the relatively short SOAs (maximum SOA of 610 ms) tested by Samuel & Weiner (2001) with the relatively long SOAs (600 – 3200 ms) tested by Samuel & Kat (2003).

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 1(bottom). A trial consisted of four sequential frames, beginning with a white fixation cross (1°) against a dark background for 250 ms. In the second frame, eight light gray circles (diameter = 3.7°) were presented for 750 ms. They were displayed in a circular fashion around the fixation cross (radius=6.8°). Empty circles alternated with circles which each contained two small (1°) figures. Each small figure was randomly selected from a set of four possibilities: red circles, red squares, blue circles, and blue squares. The cue was a new small figure (drawn randomly from the same four possibilities) that was added in Frame 3 to

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one of the four empty circles. The cue-target SOA was manipulated by varying the duration of Frame 3. In the final frame, another (randomly selected) colored square or circle (the target) was presented.

The target occurred equally often in four locations (see footnote 1), relative to the cue: in the same light grey circle (Same); 90° away – clockwise, or 90° away counterclockwise (Diff1); or 180° away (Diff2). SOAs of 200, 350, 700, 1500, 2500, and 3500 ms were chosen to span the full range of IOR that has been examined in previous research. 96 target-present cases (4 locations of first onset × 4 possible target locations × 6 SOAs) were presented in each block of the experiment. Subjects were told that two small characters would be added to the initial display on each trial, and that their task was to push the space bar when the second character appeared. 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 ms after the target onset. The inter-trial interval was 1,000 ms. 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 ms after the target onset (an anticipatory response), a brief alarm tone was presented. Similarly, if a reaction time exceeded 3000 ms, the tone was played.

Results and Discussion—An initial analysis was conducted on response accuracy. Two participants' data were excluded from further analysis because of high error rates (responses to catch trials were 7.1% and 9%; responses before the target appeared were 1% and 1%; and failures to respond were 1% and 0%). 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 error rates were very low, averaging less than 1%. Figure 1 (top) 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 ms.

Experiment 1 was designed to determine whether 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 repetition using this paradigm. That paradigm produced two central results: (1) large IOR effects that increased when the SOA was increased beyond 200–300 ms, 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 2a), while the second was indexed by any differences for targets in Diff1 versus Diff2 locations (see Figure 2b). If the current study produces comparable effects, these data points should fall within the curves defined by the previous studies. As Figure 2 illustrates, they do. Because of this, we can compare the patterns for color-based effects (Section 2) and for shape-based effects (Section 3) to the well-defined curves that are shown in Figure 2.

We conducted a two-factor analysis of variance on the reaction times. One factor was Location (Same, Diff1, and Diff2), and the second was SOA (200, 350, 700, 1500, 2500 and 3500 ms). 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, $F(5, 80)=12.52$, $p<.01$.

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Samuel and Weiner (2001) found a significant facilitation effect for their SOAs under 300 ms, and in the current study there was a similar pattern at the 200 ms SOA, with targets detected fastest at the Same location. This advantage did not reach significance compared to targets at Diff2 [$F(1,16) = .34$, n.s.], 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 $F(1,16) = 5.45$, $p<.05$]. As noted above, 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 2b), 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 Experiment 1, 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, $F(1,16) = .08$, n.s.; 2500-ms SOA, $F(1,16) = .53$, n.s.; 3500-ms SOA, $F(1,16) =2.30$, n.s.]

Having established the pattern of location-based IOR in this paradigm (for our apparatus and subject population), we now proceed to use it to test whether there are inhibitory effects of color repetition.

Section 2: Does Color Repetition Produce an Inhibitory Pattern that Matches the Pattern Found for Location Repetition?

Experiment 2

As we discussed in the Introduction, the existing literature on color-based IOR is divided among generally negative findings and the observation of small but significant effects when a neutral attractor is introduced. Even with a neutral attractor, there are suggestions that the observed effects may be due to a type of repetition blindness, rather than IOR. In short, it is currently quite unclear whether true inhibition of return can be found for non-spatial attributes. Experiment 2 was designed to test whether robust color-based inhibitory effects, with more standard temporal properties, can be demonstrated by using richer stimulus displays.

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. A new group of subjects participated in this experiment (and similarly, new groups were used in each of the following experiments).

Apparatus and Procedure: The apparatus was the same as in Experiment 1. The displays were similar, except that only two types of small figures were used: red circles and blue circles (see Figure 3, bottom). If there is color-based inhibition 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).

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Each participant was presented with three blocks of 160 trials. The 144 experimental trials within each block included the factorial crossing of 6 SOAs × 4 possible cue locations × 3 possible target conditions (Same, Diff1 and Diff2; see Footnote 1) × 2 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 he did not follow the task instructions. For the remaining 18 subjects, the error rates were very low (averaging less than 1%), and reaction times were relatively fast (mean RT = 376 ms). Figure 3 (top) presents the reaction time data, broken down by the SOA, location and color repetition conditions.

The mean correct reaction times were submitted to a three-factor analysis of variance, with degrees of freedom corrected for violations of the sphericity assumption (using the Huynh-Feldt procedure). The factors were Color 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 [$F(10,167)=1.95$, $p<.05$], and this higher-order interaction influenced two of the two-way interactions: The interactions of Location × Color Repetition [$F(2,34)=9.49$, $p<.01$] and Location × SOA [$F(10,170)=2.76$, $p<.01$] were both significant. Note that the Location × SOA interaction is in part due to typical location-based IOR: Reaction 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 [$F(5,85)=1.76$, n.s.]. All three main effects were significant [Color Repetition, $F(1,17)=4.72$, $p<.05$; SOA, $F(5,85)=16.54$, $p<.01$; Location, $F(2,34)=22.46$, $p<.01$].

The significant three-way interaction reflects the presence of a color-based inhibitory effect, but one that differed across locations. In particular, as Figure 3 shows, it is clear that color repetition produced a typical inhibitory effect (e.g., compare the result to the pattern established in Experiment 1), 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 ms SOA. For SOA = 700 ms, 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 ms), color-based inhibition in the Same location was robust [smallest $F(1,17)=7.42$, $p<.01$]. There was no hint of this effect 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.

There were two other significant facilitation effects in the analysis that were of less theoretical interest. For SOA = 200 ms, a significant effect appeared in the Diff2 location, [$F(1, 17) =6.18$, $p<.05$]; for SOA = 350 ms, a significant effect appeared in the Diff1 location [$F(1, 17) =5.48$, $p<.05$].

The results of Experiment 2 indicate that with the richer displays used by Samuel and Weiner (2001), repetition of the non-spatial attribute of color 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 3; also see the results of

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Experiment 3 below), but the general pattern is quite similar. Critically, the attribute-based effect does not appear to be independent of location, consistent with some small effects reported in previous studies using less complex displays. Experiment 3 again tests for color-based inhibitory effects in relatively rich displays, and in addition examines whether a neutral attractor plays an important role under these conditions.

Experiment 3

As we 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 2 make it clear that a color-based inhibitory effect 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 inhibition, and possibly lead to even larger effects. Thus, Experiment 3 employs the relatively rich displays used in Experiment 2, and adds a neutral central attractor between the cue and target events.

Method

Participants: Twenty two students participated in Experiment 3. 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 2. The procedure was also the same, except that a magenta-colored central cue was inserted. The bottom part of Figure 4 shows the relevant new aspects of the displays. The initial frame was the same as in Experiment 2. An additional frame (Frame 4) presented the central cue (the attractor) for 50 ms, followed by a 30 ms interstimulus interval display (Frame 5) which was similar to the cue display. Then the target display (Frame 6) appeared. In order to keep the SOAs matched to those of Experiment 2, the cue times (Frame 3) were reduced by 80 msec (120, 270, 620, 1420, 2420 and 3420 msec).

Results and Discussion—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 an intensive 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 greater than 700 ms). For the remaining 18 subjects, the error rates were very low, averaging less than 1%, and reaction times were fast (mean RT = 341 ms).

Figure 4 (top) shows the reaction time data. As in Experiment 2, we conducted a three-factor 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 × SOA, $F(10,170)=2.01$, $p<.05$; Location × Color Repetition, $F(2,34)=9.35$, $p<.01$; Color Repetition × SOA, $F(5,85)=3.09$, $p<.05$], with the Location × SOA interaction again also reflecting location-based IOR. All three main effects were also significant [SOA, $F(5,85)=2.46$, $p<.05$; Location, $F(2,34)=25.94$, $p<.01$;

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Color Repetition, $F(1,17)=8.07$, $p<.01$], with the effects of Location and Color Repetition apparently driven by the three-way interaction.

As in Experiment 2, robust color-based reaction time costs 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 ms). Also as in Experiment 2, there was no systematic inhibitory effect of color repetition at the Diff1/Diff2 locations (there was actually a small facilitation effect at Diff1 at the 700 ms SOA [$F(1,17)=5.34$, $p<.05$], and an inhibitory one for the 2500 ms SOA [$F(1,17)=5.03$, $p<.05$]); no effects reached significance in the Diff2 location.

Clearly, the results of Experiment 3 closely match those of Experiment 2; the data in Figures 3 and 4 are extremely similar. Analyses indicate that the magnitude of the inhibition in Experiment 3 is not significantly different from that of Experiment 2, $F(1,17)=.96$, n.s. In both experiments we see slower responses when cue and target share color and location, beginning with the 700 ms SOA condition. The similarity across experiments suggests that the neutral attractor is not a necessary factor in eliciting color-based inhibitory effects (for a similar conclusion regarding location-based IOR, see Pratt, O’Donnell and Morgan (2000), and Pratt (2002); for a review see Lupiáñez, 2009). 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 2 and 3, robust color-based inhibition occurs without any obvious role for the attractor.

The results in Section 2 clearly demonstrate that color repetition can produce a pattern of inhibitory effects that closely matches the pattern for location repetition, but only when the color repetition shares location as well. In the General Discussion, we will consider how these results fit with current conceptions of IOR. However, before doing so, we first test whether the attribute-based repetition effect is general, in the sense that it obtains for an attribute beyond color.

Section 3: What Properties of Stimuli are Relevant to Producing an Inhibitory Repetition Effect?

There are two goals for the experiments in Section 3. First, as just noted, we want to determine whether the results found in Section 2, using color, generalize to other visual properties of cues and targets. Thus, Experiment 4 is comparable to Experiment 2, but the repeated/nonrepeated cue-target attribute is based on shape, rather than color. The second goal in Section 3 is to test for limits on the attribute-based repetition effect. Thus, in Experiment 5 the critical stimuli also are based on shape, but the two shapes are designed to provide a much less salient difference than those in Experiment 4.

Our choice of red versus blue figures in Section 2 was guided by two factors. First, in the fairly small literature looking for IOR-like effects for non-spatial attributes, color was most frequently the attribute tested. Second, we wanted to use a distinction that was perceptually salient, and there is ample evidence in the literature, especially from studies of perceptual “pop-out” effects (e.g., Treisman & Gelade, 1980), that differences in color are quite salient (unless an experimenter intentionally chooses to reduce salience by using very similar colors).

In choosing the stimuli for Section 3, we sought an attribute that could either be salient (Experiment 4) or not (Experiment 5). For Experiment 4, we chose an open square versus a

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filled circle; for Experiment 5, we chose a filled square and a filled circle. These pairs differ in salience; for example, if they were used in a visual search paradigm, trials using the salient pairs would generate stronger "pop-out" effects than trials using the less salient pairs. In both cases, the attribute is based on the shape of the figures, and as such, we will refer to this as a shape-based manipulation. Of course, just as the color-based distinction in Section 2 was not a pure single-feature manipulation (e.g., there was no attempt to assure that the red and blue were isoluminant), the distinctions in Section 3 are not pure single-feature manipulations (e.g., in Experiment 4 the open/closed aspect of the shapes can be thought of as a type of feature; presumably, due to the different surface area of the circle and square, there will be different luminances in Experiment 5). For our purposes, what is critical is that in all of these cases the distinction is carried by non-spatial properties of the stimuli, and the distinction is more salient for the open square vs. filled circle pair than for the filled square vs. filled circle pair. For simplicity, because the critical pairs differ as a function of their shapes, we will refer to the non-spatial attribute as shape across experiments, but as noted, this is not intended as a claim that this is a unitary feature that is being manipulated.

Experiment 4

Experiment 4 uses the same design and procedures as in Experiment 2, but the small figures that are present in the displays are black open squares and black filled circles, rather that the red and blue circles. The question addressed by this experiment is whether the response time cost that we observed with color repetition will also be found with shape repetition.

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 2. The procedure was also the same, except that the critical stimuli differed in shape rather than color: The small figures were open squares and filled circles, and as Figure 5 (bottom) shows, the stimuli were black and white. If these shapes are treated as colors were in Experiments 2 and 3, 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). Moreover, if these non-spatial attributes behave the same, any inhibitory effect will be restricted to cases in which the cue and target are in the Same location.

Results and Discussion—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 (responses to catch trials: 6%, 7%, 4%; responses before the target appeared: 1%, 1%, 1%; and failures to respond: 0%, 0%, 1%). For the remaining 24 subjects, the error rates were very low, averaging less than 1%. Figure 5 (top) presents the mean target detection times, broken down by the SOA, location, and shape repetition conditions. Overall, targets were responded to relatively quickly, with a mean reaction time of 395 ms.

The mean correct reaction times were submitted to a three-factor analysis of variance, with degrees of freedom corrected for violations of the sphericity assumption. The three factors were 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 × Location

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[$F(10,230)=4.49$, $p<.01$], SOA × Shape Repetition [$F(5,115)=5.53$, $p<.01$) and Location × Shape Repetition [$F(2,46)=8.53$, $p<.01$]. The significant Location × SOA interaction reflects typical location-based IOR at the longer SOAs. All three main effects were significant [Shape Repetition, $F(1,23)=4.42$, $p<.05$; 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 inhibitory effect that differed across locations. As Figure 5 shows, robust shape-based inhibition was found at the longer SOAs, but only in the Same location. This conclusion was supported by a set of simple comparisons conducted on the data from the three conditions. For 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. In contrast, in the Diff1 and Diff2 conditions, no significant repetition effects appeared in any of the SOAs (except for a facilitatory effect at the 200 ms SOA in the Diff1 condition [$F(1,23)=6.75$, $p<.05$]).

The results of Experiment 4 are comparable to those of Experiment 2 and Experiment 3: the data in Figures 3, 4 and 5 are quite similar. In Experiment 2 and 3 we saw slower responses when the cue and target shared color and location, beginning with the 700 ms SOA condition; Experiment 4 shows the same pattern for the highly discriminable open squares versus filled circles. 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 inhibition occurs without any obvious role for the attractor, with the important qualification that the inhibition is restricted to the location of the cue.

Experiment 5

Experiments 2–4 have provided multiple demonstrations of attribute-based inhibitory repetition effects, with a time course that is similar to that found in typical location-based IOR. These three experiments have also revealed a critical constraint on observing such attribute-based effects: The attribute must repeat in the same location. In these successful demonstrations of inhibition, cues and targets not only potentially differed in an attribute, the attributes were selected to be very salient: Red and blue circles are very distinct, as are open squares and filled circles. In Experiment 5 we reduce the salience of the difference between the two critical stimuli. They are still squares and circles, but now both are filled solid figures, making them much less distinctive.

Manipulating the discriminability of the two types of stimuli can help to differentiate between the "standard" view of inhibition of return, and two recent alternatives. In the usual account, attention is drawn to an initial event (the cue), initially facilitating processing of this location (and, in some cases, object). An inhibitory process is initiated that reduces and eventually reverses the facilitation, presumably to prevent the system from getting "stuck" at the cued location. Functionally such a process would help the individual to search the environment more widely. Recently, Dukewich (2009) has reframed IOR as a form of habituation -- the perceiver becomes less sensitive to whatever has recently been perceived. This framing is related to one aspect of the view that Lupiáñez (2009) has advocated, in which the cue itself makes detection of the target more difficult. Both of these recent proposals are consistent with the results of Experiments 2–4: The greater similarity of the cue to the target when they share both location and a non-spatial attribute should enhance the inhibitory effect; when these features are not shared, there is little or no inhibition. This pattern is not as clearly predicted by the more standard view. Experiment 5 extends this line of reasoning by making all of the stimuli similar to each other. Under these conditions, the two recent approaches predict that inhibition should apply to all stimuli, not just ones that

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actually match. In essence, this reduces the situation down to pure location-based IOR, without the release from that inhibition that was observed in Experiments 2–4 when targets clearly differed in a non-spatial attribute from the cue.

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 and procedure were identical to those in Experiment 4. The only change was in the details of the critical stimuli, which were now filled circles and filled squares (see Figure 6, bottom). If inhibitory effects depend on habituation (Dukewich, 2009) or on the extent to which the cue and target are incorporated into the same object file representations (Lupiáñez, 2009), then these inhibitory effects should not show the attribute-based selectivity that was found in Experiment 4 because the uncued shapes are not different enough from the cue to escape the inhibition. Thus, Experiment 5 provides a test of the perceptual scope of repetition-based inhibition.

Results and Discussion—One subjects' data were excluded because of very long reaction times (most RTs were near or greater than 700 ms). For the remaining 26 subjects, the error rates were very low, averaging less than 1%, and average reaction time was 382 ms. The mean correct reaction times were submitted to a three-factor analysis of variance, with degrees of freedom corrected for violations of the sphericity assumption. The three factors were Shape Repetition (repeated vs. nonrepeated), SOA (200, 350, 700, 1500, 2500 and 3500 ms), and Location (Same, Diff1 and Diff2). Figure 6 (top) shows the reaction time results, broken down by these three factors. In contrast to the results in Experiments 2–4, there was no significant attribute-based modification of the inhibitory effect. This conclusion is supported by the absence of a three-way interaction [$F(10,250)=.65$, n.s.]; in the previous experiments, the three-way interaction reflected the presence of attribute-based inhibition that only occurred at long SOAs, for events in the Same location. The two-way SOA × Location was significant [$F(10,250)=4.02$, $p<.01$], whereas neither the SOA × Shape Repetition [$F(5,125)=1.78$, n.s.] nor the Shape Repetition × Location interaction [$F(2,50)=.97$, n.s.] reached significance. Note that the significant Location × SOA interaction reflects typical location-based IOR: Reaction times are much slower in the Same location than in the two Different locations, but only at the longer SOAs. The two-way interaction supported main effects of both SOA [$F(5,125)=28.21$, $p<.01$] and Location [$F(2,50)=52.85$, $p<.01$]; Shape Repetition was not significant [$F(1,25)=2.61$, n.s.].

It should be noted that Figure 6 does show somewhat higher reaction times for the condition in which shapes repeated in the Same location, at the longer SOAs, than when shape did not repeat. This nonsignificant trend suggests that there might in fact be some reduction in the inhibition for targets that differed from cues in shape, but with the poor discriminability of the filled circle/square, the effect is too weak to reach significance. We tested whether the reduced discriminability of the stimuli in Experiment 5 generated a significantly smaller attribute repetition cost than we found in Experiment 4 by conducting an additional three-factor ANOVA. Using only the data from the Same location (the only place where these effects emerged in Experiments 2, 3, and 4), the three factors were Experiment (the salient pair from Experiment 4 versus the less discriminable pair from Experiment 5), SOA (the 6 values), and Shape repetition (repeated versus nonrepeated). The significant three-way interaction in this analysis confirms that the SOA × Shape repetition interaction (i.e., non-

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spatial attribute repetition effect) was bigger in Experiment 4 than in Experiment 5, $F(5,115) = 2.38$, $p < .05$. Thus, the results of Experiment 5, together with the results from Experiments 2, 3, and 4, confirm that the degree of inhibition depends on the similarity of the cues to the targets, with spatial similarity playing a dominant role.

General Discussion

As many authors have noted, attentional selection is necessary because the essentially infinite amount of incoming sensory information exceeds the processing capacity of our perceptual and cognitive systems. Over the course of the last quarter century, investigators have built on Posner and Cohen's (1984) seminal report of a particularly interesting form of attentional selection: inhibition of return. Studies in this research domain have determined important properties of this phenomenon, such as its spatial and temporal limits. For the time course, Samuel and Kat (2003) have collected the results from dozens of studies that collectively flesh out Posner and Cohen's original finding of a repetition advantage for about 200 ms, 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.

Although the vast majority of work on IOR has focused on inhibition defined in spatial terms, the important demonstration of inhibition focused on particular objects, by Tipper and his colleagues (e.g., Tipper et al., 1991, 1994, 1999), raises a number of critical theoretical issues. Most notably, this finding calls for an understanding of the way that attention is allocated: 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, and color? Although a few studies 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, and more critically, the time course was entirely different. The effects tended to be largest at the shortest SOAs, unlike typical IOR effects, suggesting that the attribute-based effects might be a type of repetition blindness (Kanwisher, 1987, 1991), rather than real inhibition of return.

In Experiments 2 and 3 of the current study, inhibition tied to color repetition was both larger than the effects previously reported, and it followed a similar time course to that of location-based IOR, emerging after the 350 ms 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). Experiment 4 replicated this result, using repetition of shape rather than color. Given that Experiments 2 and 3 differed in terms of the presence or absence of a neutral attractor (and that Experiment 4 had no such attractor), the similarity of the results argues against any critical role for the attractor in these more complex displays. Law et al. (1995) had introduced the attractor in the 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. Pratt (2002; Pratt, O'Donnell, & Morgan, 2000) has pursued the role of the neutral attractor, but given the robust effects of Experiments 2, 3 and 4, this may prove to be of more methodological than theoretical importance.

It is possible that the neutral attractor may be serving as a kind of separator that contributes to a form of repetition blindness. As we have noted, some researchers (e.g., Fox & de Fockert, 2001; Taylor & Klein, 1998) have argued that the color-based repetition disadvantage is not really inhibition of return, but is instead a type of repetition blindness.

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Kanwisher (1987, 1991), who introduced this phenomenon, has shown that these failures to detect repeated items 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 is additional evidence that the effects found here are unlikely to be a variant of repetition blindness. This view is also reinforced by the robust effects found for SOAs over two seconds, well beyond the range of repetition blindness.

A key finding in our experiments was that the robust repetition-based impairment of detection speed was completely localized: IOR-like effects were found only when an attribute was repeated in the Same location; no such effects occurred for either of the Different locations. These results are consistent with Klein's (1980) proposal that a subject's attention may be allocated not to a position in visual space but to the set of known properties of the expected (cued) stimulus. Following this perspective, Klein and Hansen (1990) suggested that the facilitatory effect is not cast on all of the items at a cued location, but is instead limited to only those similar to the cue[2]. This restriction imposes strong theoretical constraints. In particular, it requires that the effects operate on features other than location, but that location must still be the "indispensable attribute" that Kubovy (1981) has identified. The results of Experiment 5 provide a very useful framework for interpreting the patterns of Experiments 2–4. Specifically, they suggest that a salient change in a non-spatial attribute such as color or shape is sufficient to provide a release from the inhibition that would otherwise apply.

Note that this analysis supports a model that can simultaneously account for the similarities between non-spatial features (e.g. color and shape) and spatial location (since feature repetition modulates inhibitory effects), while also clearly addressing the special role of spatial location. Two recent conceptions of IOR (Dukewich, 2009; Lupiáñez, 2009) seem to offer these properties in ways that the more traditional view of IOR might not. In the most widely accepted view, the cue summons attention (automatically), which will usually produce facilitation at that location. However, a counteracting inhibitory process is also initiated, which reduces and eventually reverses the initial facilitation. There are two variants of this theory that differ in the timing of the inhibitory process. On one account it must follow the initial facilitation (thus requiring that facilitation be observed initially), whereas on the other account the inhibition begins simultaneously with the facilitation, with the observed results then depending on procedural details that may favor one process over the other.

As Lupiáñez (2009) has pointed out, the term "inhibition of return" unfortunately conflates the empirical finding of a delayed inhibitory effect in a cue-target situation with the traditional account of that empirical finding. That is, the empirical finding is a delayed cost to repetition; the theoretical account is the allocation and subsequent inhibition of allocation of attention to a particular location (or object).

The empirical result is potentially amenable to a number of theoretical explanations, not all of which involve the pattern of allocation/non-allocation implied by IOR. For example, Dukewich (2009) has recently offered a conception of the IOR results in terms of a habituation model that does not include the traditional components. In her model, the typical reduction in performance for the target is attributed to the very general phenomenon of

[2] Klein's (1980) study involved endogenous attention rather than the exogenous orienting (also see Ivanoff & Klein, 2004) in the current study. Nonetheless, the similarity between his suggestion and the present findings is intriguing. We thank Raymond Klein for bringing this paper to our attention.

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habituation: The presence of a similar preceding event (the cue) leads to a weakened orienting response to the target, a pattern that has been shown in many domains: “orienting -- just like any other response of the nervous system -- is subject to habituation” (p.249). In general, habituation is strongest for the exact repetition of a stimulus, with weaker habituation as the stimulus differs across presentations. The results of the current study can easily be framed within this perspective: Slowed responses (due to habituation) were observed only when the targets were similar enough to the cues in terms of both their features (color, or shape), and location (Same, but not Different). In Dukewich's model, these inhibitory effects only emerge after a delay because at short intervals the cue itself adds enough activation to the target to more than compensate for any habituation. This model satisfies the need for space to be both like and dislike other features: The similarity function can use location much as it uses features such as color and shape, while the habituation is of responses that are spatially directed; space is unique in having both an input and an output role (Barry, 2006).

Dukewich's (2009) model is an attempt to place some of the ideas that Lupiáñez and his colleagues (e.g., Lupiáñez, 2009; Lupiáñez, Milan, Tornay, Madrid, & Tudela, 1997) have offered into a more general framework (see Francis & Milliken, 2003, for a related view). Lupiáñez has argued that the particular pattern of facilitation or inhibition will depend both on the timing of targets and cues, and on the nature of the task that subjects are given. He suggests that performance depends on how at least three factors interact. Two of these involve spatial aspects, and in both cases, the factor facilitates performance. Essentially, the presentation of a cue provides spatial information, and that information can be used to enhance processing of the target (see Heinke & Humphreys, 2003, for a similar perspective). These facilitative spatial effects are strongest with short cue-target delays. The third factor is inhibitory: The presentation of the cue can make it more difficult to detect the onset of the target. This effect is also strongest at short delays, but it still has a robust influence even at longer delays. Lupiáñez argues that this onset detection factor reflects the operation of object files (e.g. Kahneman & Treisman, 1984; Kahneman et al, 1992). When cues and targets are very similar, the target may get absorbed into the object file created for the cue, making it difficult to detect. This would delay detection performance, producing the standard IOR effect.

The perspective provided by Lupiáñez (2009) can nicely account for our central result: IOR-like effects occur for attributes such as color and shape, but only when location is shared. This pattern falls out of the fact that object files are indexed by location. And, sharing attributes would make cues and targets more likely to be mapped onto a single object file (see Hommel, 2004, for a similar suggestion). This approach can also potentially account for the contrasting results in Experiments 4 and 5. Recall that Experiment 4 produced a significant shape-based inhibitory effect; responses were delayed for targets that shared both shape and location with a cue. In Experiment 5 two less discriminable shapes were used. For these less discriminable shapes, the apparent lack of shape-based IOR is in a sense misleading, because what presumably happened was that the similar shapes were both absorbed by the object file. This added a similar cost to the object detection process for these cases, reducing the difference between repeated and non-repeated items. As a result, inhibitory effects were found regardless of shape matching.

Although we have focused on drawing distinctions among the three competing descriptions of inhibition of return, there is a common basis among them that is worth noting. Each theory ultimately provides one mechanism that is fundamentally facilitative, and one that is fundamentally inhibitory. This is explicit in the traditional account, but is perhaps less evident in the two recent alternatives. Dukewich (2009) emphasizes the inhibitory aspect – habituation – but also notes that overlapping processing of a cue and target can facilitate

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target processing. Lupiáñez (2009) has two facilitative processes in his model that are based on spatial localization, and one inhibitory process that can occur when a target gets absorbed into the cue's object file.

This distinction between spatial localization and stimulus processing at a particular location is reminiscent of a distinction that Algom and his colleagues (e.g., Chajut, Schupak, & Algom, 2009; Shalev & Algom, 2000) have drawn. These authors note that the literature provides two quite different notions of attentional focus. The first notion is the one that drives the two processes that provide facilitation for Lupiáñez (2009): A cue of some type can allow the observer to direct attention to one location (potentially at the expense of other locations). The original cueing studies by Posner and his colleagues (Posner, 1980; Posner & Cohen, 1984; Posner et al., 1985) are classic examples of this tradition in attention research. The second tradition, exemplified by Garner (1974) and Stroop (1935), focuses on dimensional analysis of a particular stimulus – is it red or blue, round or square, big or small, etc. Viewed this way, the two recent theories actually appear to assign facilitation and inhibition in opposite ways: The inhibitory effect for Dukewich is habituation of the orienting response, which attaches the inhibition to the process of directing attention to the relevant location; facilitation in this model comes from shared dimensional processing of the target and cue. For Lupiáñez, the roles are reversed: The inhibition comes from a target being absorbed by a cue's object file (the site of dimensional processing), and the facilitation is primarily due to faster localization of attention (though there is a role for it in dimensional processing as well).

To the extent that the two new models differ in their assignment of facilitation and inhibition to different aspects of attention, it may be possible to choose between them by seeing which assignment better fits the facts. Not surprisingly, the relevant facts are not really yet available. However, some recent modeling work offers an interesting approach that might be able to provide the necessary data. Brown and Heathcote (2008) described a linear ballistic accumulator model of decision making that is a variant of random walk (e.g., Link & Heath, 1975) or diffusion (e.g., Ratcliff, 1988) models. In these kinds of models, decisions (e.g., was a target red or blue) are viewed as a process of accumulating evidence until it exceeds a threshold for one response (e.g., red) or another (e.g., blue). This can be thought of as starting at some neutral point, and gradually moving toward one threshold or the other. In this conception, critical parameters involve the location of each threshold relative to the starting point, and the rate of accumulating information: If such accumulation is fast, and a threshold is near the starting point, a rapid response can be made.

Farrell, Ludwig, Ellis, and Gilchrist (2010) applied Brown and Heathcote's (2008) model to a set of data they collected in an experiment examining inhibition of return. They were studying a variant of IOR that involves a delay in saccadic eye movements toward a recently viewed location. There were two factors in the experiment: (1) whether an eye movement was being directed toward the most recently viewed location, and (2) the probability of a given location being one that was supposed to be attended. The first factor is the basic IOR manipulation – there should be slower movements toward the most recently viewed location than to other locations. Both parameters affected performance as one might expect, with IOR for the first factor, and faster responses for the more likely locations. Farrell et al. were primarily interested in which parameter of the model each factor affected. They found that the IOR factor affected the rate of evidence accumulation, while the probability manipulation affected the setting of the response threshold. If we associate the evidence accumulation rate with processing of a stimulus at a particular location (dimensional processing) and the probability manipulation with the stimulus detection factor, these results are more consistent with the mapping of inhibition and excitation in the Lupiáñez (2009) model than in the Dukewich (2009) model. Clearly, this is just a preliminary and speculative

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suggestion, but the technique does seem to be a promising way to sort out rather subtle differences among the competing models.

Conclusion

The current study provides the first clear demonstration that features other than location can play a critical role in generating inhibitory effects that match the size and timing of "classic" inhibition of return. Critically, we find that this pattern can only be observed when the non-spatial features repeat in the same location. Moreover, cue-target discriminability also determines whether attribute-based effects will be seen. If we consider the selective effects found in Experiments 2–4 together with the non-selective (by shape) effects found in Experiment 5, then the most parsimonious account is that non-spatial features can allow stimuli to escape the normal inhibitory effect. Thus, we can think of mismatching non-spatial features as providing a release from the inhibition.

This analysis of the results does not fit particularly well with the typical view of IOR as a specialized process to force attention away from a recently selected locus. Rather, it is more consistent with two recent theoretical perspectives (Dukewich, 2009; Lupiáñez, 2009) that do not rely on the notion of attention occupying and then leaving a particular location. A particularly appealing consequence is that IOR research may be accommodated within theories that have a great deal of other kinds of empirical support, such as object file theory (and more generally, event perception) and habituation. At this point, the available data do not provide a definitive choice between the habituation (Dukewich, 2009) and object file theory (Lupiáñez, 2009) perspectives. However, it should be possible to draw upon established properties of habituation and object file theory (e.g., capacity, time course) to develop empirical tests that can distinguish them, and to use other analytic techniques (e.g., Brown & Heathcote, 2008; Farrell, Ludwig, Ellis, and Gilchrist, 2010) to provide critical tests. However such future tests may turn out, the current results suggest that just as inhibitory effects may be eliminated by changes in non-spatial attributes, it may be possible to eliminate the notion of a particular process devoted to inhibiting the return of attention.

Acknowledgments

The first author thanks John X. Zhang, Alan C. Wong, and Raymond Klein for their helpful comments during the early stages of this research, and Ewart Thomas for his statistics advice. Thanks also to Shuliang Zheng, and Mengling Hu of Peking University for their assistance in conducting the experiments. In addition, we thank Yan Bao for providing lab facilities that enabled some of the experiments to be run in Peking University, and Raymond Klein for very constructive suggestions during the review process. We thank Donna Kat for her expert help in preparing the figures. We are pleased to acknowledge support from NIH grants R01-51663 and R01-059787.

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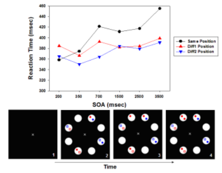

Figure 1.

Top: Target detection times of Experiment 1, broken down by Location (Same, Diff1 and Diff2) and Stimulus onset asynchrony (SOA); Bottom: Example of the sequence of events for a sample trial in Experiment 1 (Note: not drawn exactly to scale; in the actual displays, each frame was a 480 × 640 pixel display).

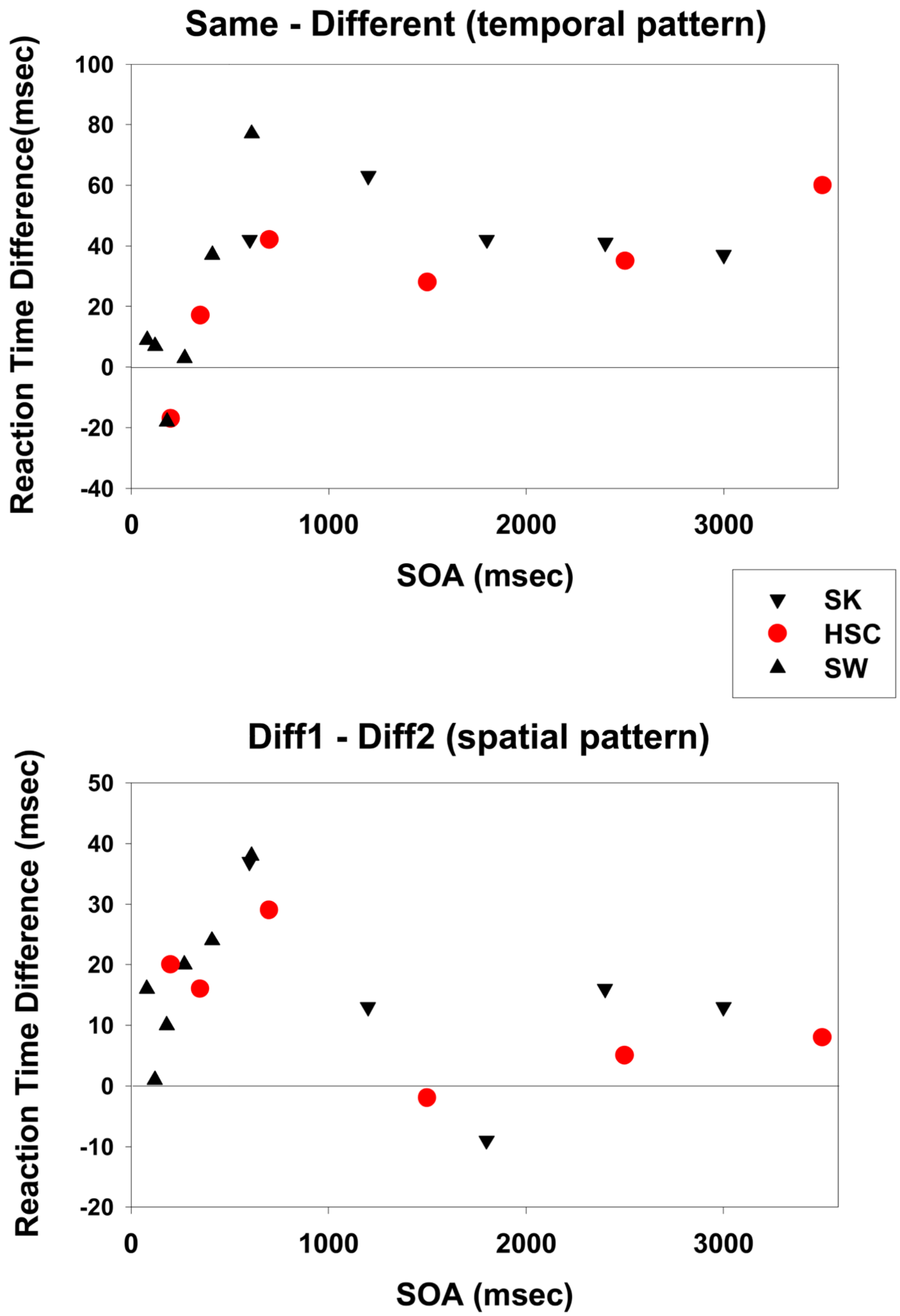

Figure 2.
Top panel: IOR effects (difference in RT between Same and average of the two Diff locations), from Samuel & Weiner (2001; Experiment 1) [upward triangles], Samuel & Kat (2003; Experiment 1) [downward triangles], and the current study's Experiment 1 [circles]. Bottom panel: Spatial differences in IOR (difference in RT between Diff1 location and Diff2 location); same symbols as top panel.

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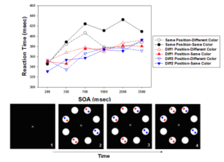

Figure 3.

Top: Target detection times of Experiment 2, broken down by Color (repeated, nonrepeated), Location (Same, Diff1 and Diff2) and Stimulus onset asynchrony (SOA); Bottom: Example of the sequence of events for a sample trial in Experiment 2 (not drawn exactly to scale).

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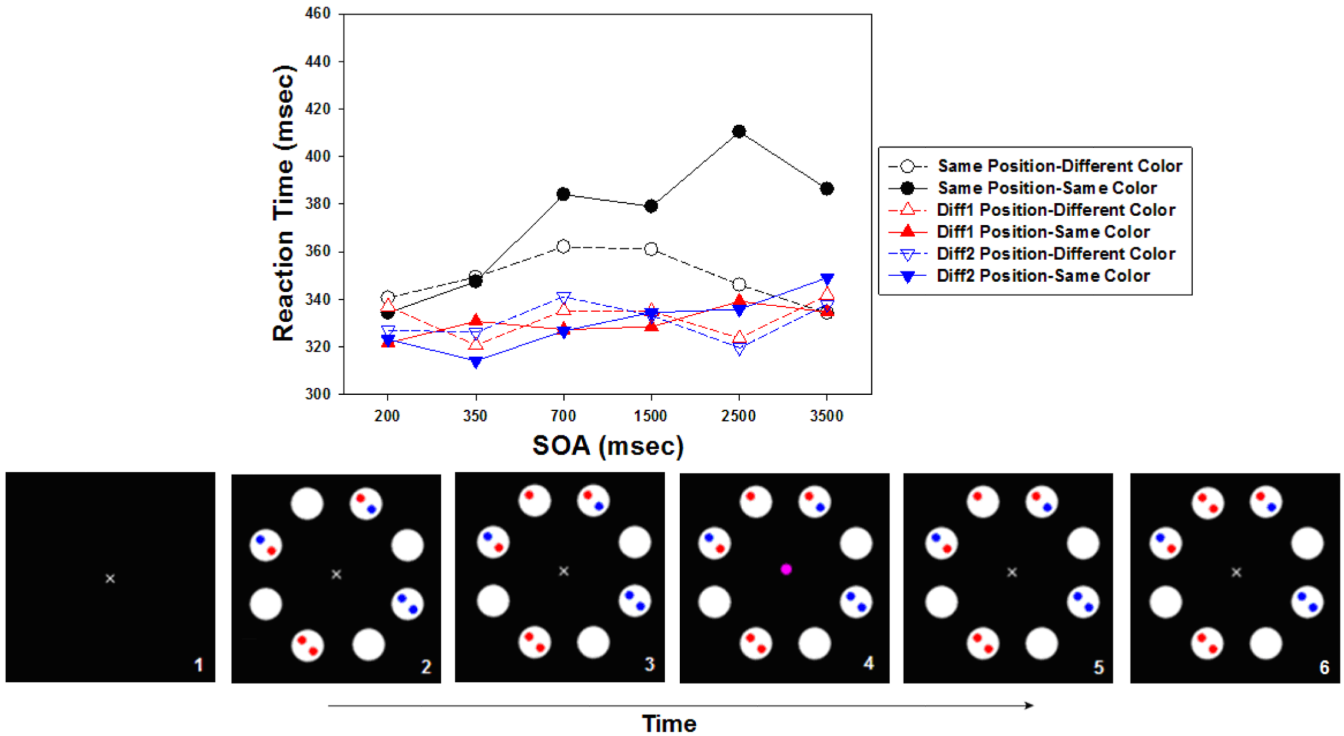

Figure 4.
Top: Target detection times of Experiment 3, broken down by Color (repeated, nonrepeated), Location (Same, Diff1 and Diff2) and sSimulus onset asynchrony (SOA); Bottom: Example of the sequence of events for a sample trial in Experiment 3 (not drawn exactly to scale).

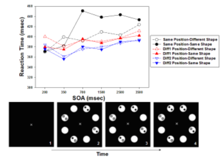

Figure 5.
Top: Target detection times of Experiment 4, broken down by Shape (repeated, nonrepeated), Location (Same, Diff1 and Diff2) and Stimulus onset asynchrony (SOA); Bottom: Example of the sequence of events for a sample trial in Experiment 4 (not drawn exactly to scale).

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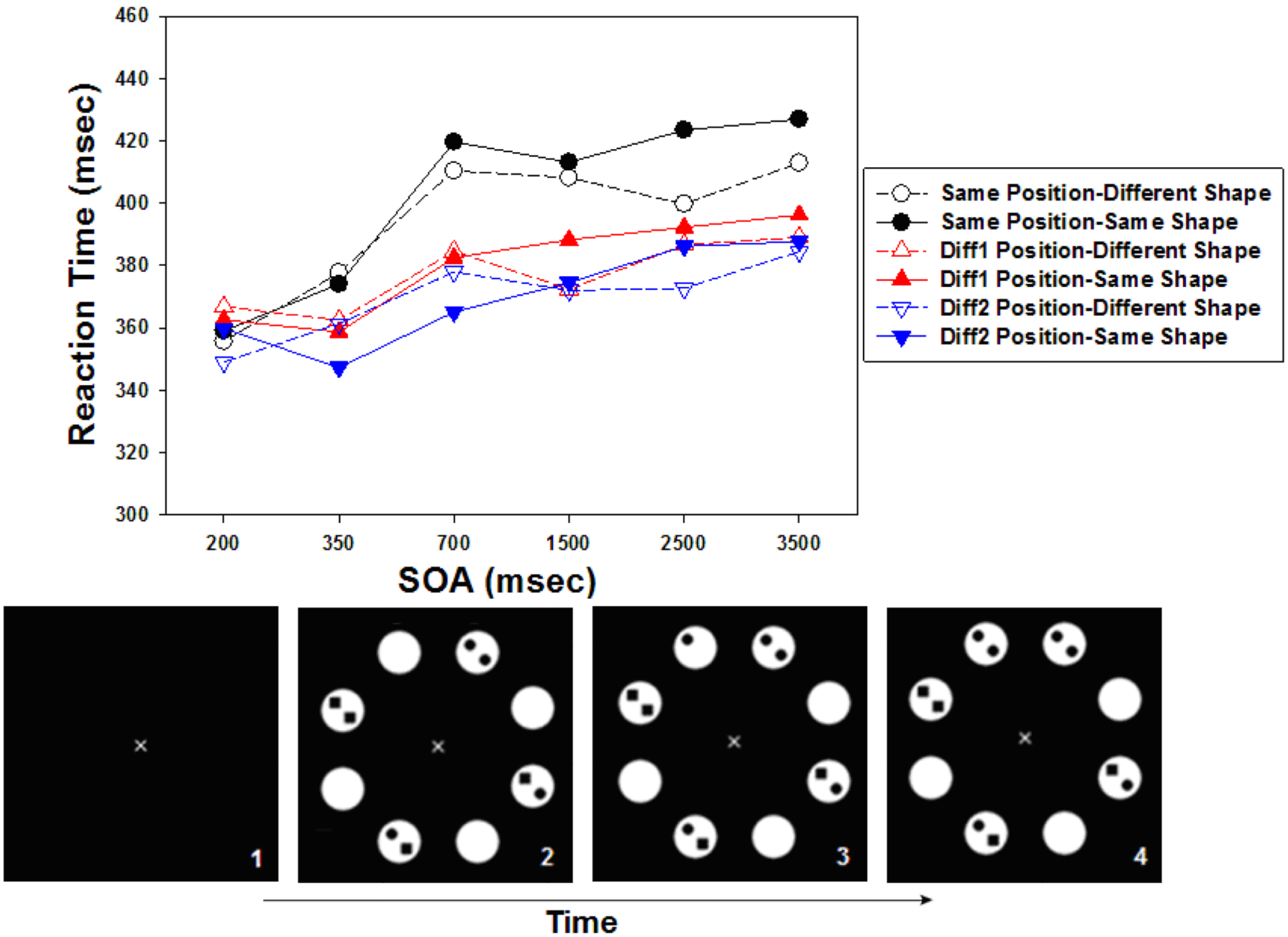

Figure 6.
Top: Target detection times of Experiment 5, broken down by Shape (repeated, nonrepeated), Location (Same, Diff1 and Diff2) and Stimulus onset asynchrony (SOA); Bottom: Example of the sequence of events for a sample trial in Experiment 5 (not drawn exactly to scale).