Published in final edited form as:
J Exp Psychol Hum Percept Perform. 2007 December ; 33(6): 1322–1334. doi:
10.1037/0096-1523.33.6.1322.

Inhibition of Return and Object-based Attentional Selection

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Abstract

Visual attention research has revealed that attentional allocation can occur in space- and/or object-based coordinates. Using the direct and elegant design of R. Egly, J. Driver and R. Rafal (1994), we examine whether space- and object-based inhibition of return (IOR) emerge under similar time courses. The present experiments were capable of isolating both space- and object-based effects induced by peripheral and back-to-center cues. They generally support the contention that spatially non-predictive cues are effective in producing space-based IOR at a variety of SOAs, and under a variety of stimulus conditions. Whether facilitatory or inhibitory in direction, the object-based effects occurred over a very different time course than did the space-based effects. Reliable object-based IOR was only found under limited conditions and was tied to the time since the most recent cue (peripheral or central). The finding that object-based effects are generally determined by SOA from the most recent cue may help to resolve discrepancies in the IOR literature. These findings also have implications for the search facilitator role IOR is purported to play in the guidance of visual attention.

Considerable research has been dedicated to characterizing attentional allocation in visual displays. Among the many paradigms developed to investigate visual attention, the spatial cueing paradigm developed by Michael Posner (1980) has been instrumental in revealing many aspects of attentional allocation. In its most simple form, the cueing paradigm manipulates viewers' covert attention with a salient peripheral change (a cue) before they are asked to detect a target. By changing the spatial relationship between cue and target, i.e. whether they are spatially co-located or not, attentional effects can be measured through costs and benefits in response time (RT). This simple yet elegant procedure has been used to reveal two features of visual attention that are the focus of the present research: inhibition of return (IOR) and object-based selection.

Inhibition of return is one of two major reflexive attentional processes thought to contribute to detection differences at cued versus neutral[1] or uncued locations (Klein, 2000;Posner & Cohen, 1984). Inhibition of return is demonstrated by *slowed* RTs to cued target locations when compared to uncued target location RTs. In contrast, facilitation is revealed when detection at cued locations is *speeded* relative to uncued locations. The emergence of one effect or the other is typically linked to stimulus onset asynchrony (SOA) and/or the predictive value of the cue.

Some investigators have argued that facilitation and inhibition reflect different attentional mechanisms, rather than two phases of one attentional system (e.g., Bao & Pöppel, 2006; Berger & Henik, 2000; Rafal & Henik, 1994; Tassinari, Aglioti, Chelazzi, Peru & Berlucchi,

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[1]In later experiments, the neutral condition has often been excluded, as both facilitatory and inhibitory response time patterns are consistently found.

1994; Tipper et al., 1997; or see Rafal & Robertson, 1996 for a discussion). Presumably, both facilitatory and inhibitory mechanisms function simultaneously, and any detected effect is the result of one of the mechanisms overcoming the other. Facilitation of target detection tends to occur when SOA (time from cue onset to target onset) is shorter than 200–300 ms (Klein, 2000; Posner & Cohen, 1984) or when the cue predicts an upcoming target location, even at longer SOAs (e.g., Danckert, Maruff, Crowe & Currie, 1998; Egly, Driver & Rafal, 1994; Posner, 1980). Although debate continues concerning the necessary and sufficient conditions under which inhibition occurs, certain general parameters have been found to more consistently elicit IOR. When SOA is prolonged to longer than 200–300 ms and cues carry no predictive information about upcoming target locations, response times (RTs) to cued target locations are typically slowed (Klein, 2000; Posner & Cohen, 1984). Experiments revealing IOR often include a second cue at the central fixation location (i.e., a back-to-center cue) before target onset (e.g., Jordan & Tipper, 1998, 1999; Posner & Cohen, 1984), although space-based IOR has been demonstrated without the use of these central cues (e.g., Pratt & Fischer, 2002; Pratt & McAuliffe, 1999; Sapir et al., 1999). Inhibition has been theoretically explained as an efficient mechanism to facilitate visual search: once a location or object has been searched, attention is directed elsewhere to a new location or object (e.g., Danziger, Kingstone & Snyder, 1998; Klein, 1988; Posner & Cohen, 1984; Tipper, Driver & Weaver, 1991).

In addition to revealing a biphasic pattern of response times (facilitation preceding inhibition when plotted against SOA), the Posner cueing paradigm has been used to show that attentional selection occurs not only for spatial locations, but also for objects. Distinguishing attention to space and objects is a generally difficult problem given that objects appear in and occupy spatial locations. When a spatial location is cued, the object inhabiting that location may also be cued, making it problematic to decipher when attentional allocation is directed to objects and/or to spatial locations.

A study by Egly, Driver and Rafal (1994) was decisive in establishing that facilitation could appear not only at a cued location (a space-based effect), but also within cued objects at uncued locations (an object-based effect). They presented a display with two objects (rectangles), one of which was cued at one end or another, and targets followed in one of three critical conditions: at the *cued* location, at an *uncued* location in the cued object (*within-object*) or at an *uncued* location in the uncued object (*between-object*). By placing the objects as far apart as they were long, the spatial distance between the cued location and both uncued locations are held objectively equal (see Figure 1). By comparing RTs to targets appearing in the two *uncued* locations, Egly and colleagues argued that attentional shifts *within* objects were consistently faster when compared to equivalent shifts *between* objects. An RT difference to detect targets appearing in *within-object* versus *between-object* conditions will henceforth be termed an *object-based effect.* Originally, a facilitatory object-based effect was reported by Egly and colleagues (1994) who used a predictive cue and a 300-ms SOA. Facilitatory object-based effects have been replicated in a variety of displays and under various conditions (e.g., Abrams & Law, 2000; Macquistan, 1997; Moore, Yantis & Vaughan, 1998; Moore & Fulton, 2005; Pratt & Sekuler, 2001; Robertson & Kim, 1999; Vecera, 1994).

Both space- and object-based IOR have been reported in the literature as well (e.g., Tipper, Jordan & Weaver, 1999). As previously mentioned, a common hypothesis concerning the function of IOR is that it acts as a biasing mechanism away from previously-examined locations in order to facilitate search. However, in a search situation, it is often an object that we seek, not a location (as argued by others, e.g., Tipper, Driver & Weaver, 1991). Returning attention to an object that has already been rejected as a non-target would decrease search efficiency. It would then seem that object-based IOR should be at least as strong and as prevalent as space-based IOR. Findings of object-based IOR are therefore vital to theories claiming that IOR functions to improve the allocation of visual attention.

In an experiment inspired by the findings of Egly and colleagues (1994), Jordan and Tipper (1999) reported the existence of object-based IOR using a similar rectangle display and cueing procedure. In their experiment, they extended the SOA to 1166 ms and removed the predictability of the cue (i.e., they used a purely exogenous cue) to more effectively elicit IOR. Jordan and Tipper's results demonstrated slowed RTs to *cued* locations relative to both *uncued* locations, i.e., space-based IOR. Object-based IOR also appeared when comparing uncued conditions: *within* RTs were *slowed* relative to *between* RTs (i.e., the mirror image of the facilitation reported by Egly et al., 1994). These results were taken to indicate that IOR, like facilitation, occurred in both space- and object-based coordinates.

Various studies have shown that visual attention is sensitive to space, objects or a combination of the two (e.g., Behrmann & Tipper, 1999; Duncan, 1984; Egly et al., 1994; Gibson & Egeth, 1994; Jordan & Tipper, 1998; Schendel, Robertson & Treisman, 2001; Tipper, Jordan & Weaver, 1999). However, not all studies, especially those with more complex displays, have supported the findings of object-based IOR (Schendel & Robertson, 2000, submitted; Schendel, Robertson & Treisman, 2001). In those studies, the observed IOR was limited to space: it seemed to be both insensitive to object shape and to three-dimensional cues in complex displays. Facilitation, however, was found and did extend to objects. The current series of experiments sought to understand the conflicting object-based findings more thoroughly. Namely, we chose to explore whether space- and object-based effects coexist with simple stimuli (a two-rectangle display), and whether these effects emerge simultaneously. The present results support the conclusion that object-based IOR is susceptible to minor design manipulations, while space-based IOR is consistently found. We also find that if object-based IOR emerges, it does so only transiently.

Experiment 1

The first experiment was a direct replication of that run by Jordan and Tipper (1999), to verify that the inhibitory component of visual attention is modulated by both space and object configuration. As mentioned above, although this issue has been addressed before with the conclusion that IOR is susceptible to both spatial and object configurations (Jordan & Tipper, 1998, 1999; Tipper et al., 1999), the literature is not in complete agreement on this point. Many differences exist in the designs of the studies. Some differences are subtle, such as differences in contrast polarity between objects and background, while others are more pronounced, such as the use of simple two-item stimulus displays compared to more complex displays. Therefore, we begin with a replication of Jordan and Tipper's (1999) positive findings of concurrent space- and object-based IOR[2].

Based on the use of a non-predictive cueing procedure and a long (1176 ms) SOA, and consistent with the literature, we expected to find IOR at the *cued* location, i.e., an inhibitory space-based effect. Our prediction regarding the object-based effect (differences between *within* and *between* conditions) was motivated by the search facilitation hypothesis discussed above. If IOR facilitates visual search for objects in the environment, then we should find *object-based* inhibition, as did Jordan and Tipper (1999). Specifically, targets appearing in the *within* conditions should be detected more slowly than those appearing in the *between* conditions. In contrast, if IOR operates only in space-based coordinates while facilitation extends to objects, as suggested by other findings (e.g., Schendel & Robertson, 2000; submitted), a cue may simultaneously produce *spaced-based* IOR and *object-based* facilitation (*cued* slower than *uncued* RTs and *within* faster than *between* RTs).

[2]Jordan and Tipper (1999) were also investigating whether object-based effects could be found using amodally completed objects. That and a control condition constituted the other between-subject conditions, each with 12 participants.

Methods

Apparatus—Testing was conducted on a PC desktop running Presentation software to display stimuli, and record reaction times and errors (http://nbs.neuro-bs.com/). Participants responded by pressing the keyboard spacebar with their left index finger, and with a left mouse button press using their right index finger. We used a CCD camera (Wotec WAT-502A model with a 16-mm lens) connected to monitor out of participants' sight for the purpose of monitoring eye movements. Prior to the experiment, the experimenter adjusted the focus and depth of field such that participants' eyes were clearly visible on the monitor.

Participants—Seventeen University of California undergraduate summer school students participated in Experiment 1 for course credit. All provided informed consent prior to participation. Two participants were replaced: one for an inability to maintain visual fixation, the other for making 15% false alarms on *catch* trials.

Stimuli—Black rectangles and the central fixation crosshair were presented on a white background[3]. Targets and cues were gray. The display spanned 7.8° of visual angle. However, since the rectangles were rotated either + or − 45° from upright, the horizontal and vertical visual angle spanned 10.9°. The display's fixation crosshair subtended 0.4° and its two flanking vertical rectangles each subtended 1.9° × 7.8°. The outside edges of the rectangles were 7.8° from each other. The central cue was simply a change in the fixation color from black to gray. The peripheral cues[4] were 3-pixel width square outlines (subtending 2.3° × 2.3°), flanking and centered at the end of the rectangle. Targets were solid gray squares, subtending 1.4°. They appeared at the end of each rectangle such that their center corresponded to the peripheral cue's center (see Figure 1). Participants sat at a distance of 40 cm from the screen.

Design—All participants were exposed to five trial types (*cued*, *within*, *between*, *opposite* and *catch*) in both + and − 45° orientations. Cues and targets appeared equiprobably in all four locations. All trial types and orientations were randomly intermixed. To measure space-based effects, *cued* RTs were compared to *uncued* RTs (the mean of the two equidistant uncued RTs, i.e., *within* and *between*), although all three comparisons to *uncued* conditions are presented. This approach was used since it is unclear which uncued condition represents a "pure" shift of spatial attention. It may be that RT differences reflect performance benefits to orient within an object, or a cost to orient between objects; the mean of the equidistant *uncued* RTs is an agnostic compromise. Object-based effects were revealed by comparing *within* and *between* RTs.

Procedure—All procedures were adopted to approximate those used by Jordan and Tipper (1999). Participants completed 40 practice trials to familiarize themselves with the task while being monitored by the experimenter for task compliance. Participants then completed five blocks of 40 trials, totaling 200 experimental trials. *Catch* trials were presented randomly on 20% of the total trials. Participants began each trial by pressing a space bar in response to a screen reading: "Please press the space bar to start trial." A blank white screen was presented for 1000 ms as the inter-trial interval (ITI).

All trials had the following timing parameters: after beginning the trial with a space bar press, participants saw the fixation and oblique rectangles displayed for 1000 ms, a peripheral cue appeared for 82 ms, after a 506-ms delay, the central cue appeared for 82 ms, and after another 506-ms delay, a target appeared (except during *catch* trials) for 82 ms. Participants responded to targets with a mouse press, or the trial ended after a 1000-ms delay. The 1176-ms SOA

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[3]Jordan and Tipper (1999) used black rectangles, a gray background and white targets and cues. However, from other studies, we discovered that black rectangles produced white after images that are visible on gray backgrounds (creating the illusion of four rectangles). To avoid this problem, we used a white background, black rectangles and fixation crosshair, and gray targets and cues.

[4]Although this brightening was uninformative, it will be called a "cue" to be consistent with the literature.

approximated that of Jordan and Tipper (1999) and was the closest our experimental set up could approximate their 1166-ms SOA due to the limitations of how our software interacted with the monitor refresh rate.

Participants were encouraged to respond as quickly as possible regardless of where the target appeared, and to withhold response if no target appeared. They were informed that the cue was not predictive of subsequent target location. They were also instructed to maintain central fixation whenever stimuli were present. Throughout practice and the experimental trials, the experimenter monitored central eye fixation. During practice, participants were given verbal feedback when fixation was not maintained. During the experiment, the experimenter marked trials with eye movements for exclusion (Jordan and Tipper [1999] only monitored during practice).

Results

Orientation (+/−45°) and Cueing (*cued*, *within*, *between*, *opposite*) were entered as within-subjects factors into an ANOVA on median RTs for correct responses (see Figure 2). Excluded from the analyses were data from trials in which RTs were faster than 100 ms (*M*=3.2%) and slower than 1000 ms (*M*=0.0%). False alarms (*M*=1.3%), misses (*M*=0.3%), or trials accompanied by eye movements (*M*=1.6%) were also omitted.

Orientation—There was neither a main effect of Orientation nor an interaction with Cueing (*F*-values<1.0).

Cueing—A main effect of Cueing was found [$F(3,48)=20.7$, MSE=807, $p<0.001$]. Space-based IOR was revealed: *cued* RTs were 28 ms slower than the *uncued* RTs [$t(16)=-3.623$, $p<0.01$]. Compared to each uncued condition, cued RTs were 21 ms slower than *within* RTs [$t(16)=-4.56$, $p<0.05$], 36 ms slower than *between* RTs [$t(16)=-4.37$, $p<0.001$] and 52 ms slower than *opposite* RTs [$t(16)=-5.98$, $p<0.001$].

Object-based IOR was also revealed: *within* RTs were 15 ms slower than *between* RTs [$t(16) = -2.68$, $p<0.05$].

Discussion

The current experiment replicated the findings of Jordan and Tipper (1999). We found concurrent space- and object-based inhibition with a SOA of 1176 ms. Notably, minor differences in experiments (e.g., the stimulus polarity and 10 ms difference in SOA between ours and Jordan and Tipper's experiment) were of no consequence to replicating their object-based results (compare our 15 ms object-based inhibitory effect with their 12 ms effect)[5].

Experiment 2

In order to return to our original question: whether space- and object-based cueing effects emerge differently across time, we carried out a second experiment. In this experiment, we used a two-SOA design. We retained a long SOA (1220 ms) in which we expected to replicate the space- and object-based inhibition of Experiment 1. We also included a short SOA (340 ms) to test whether space- and object-based inhibition emerge simultaneously. We used a SOA that was the shortest likely to produce space-based IOR (as discussed above, inhibition is usually found with SOAs longer than 200–300 ms). The question addressed was whether space-based IOR would be accompanied by object-based IOR at such a short delay.

[5]One difference was found between experiments: in our experiment *opposite* RTs were reliably different from *between* RTs [$t(16)=-3.65$, $p<0.05$].

Methods

All methods are identical to Experiment 1, unless indicated otherwise.

Participants—Course credit was awarded to seventeen University of California undergraduate students after they provided informed consent. Two participants were again replaced: one for an inability to maintain visual fixation and the second for excessive false alarms on *catch* trials (over 13%).

Stimuli—Stimuli were identical to those used in Experiment 1.

Design—All participants were exposed to five trial types (*cued*, *within*, *between*, *opposite* and *catch*) in both + and −45° orientations. All trial types and orientations were randomly intermixed.

Procedure—Participants completed 80 practice trials to familiarize themselves with the task while being monitored by the experimenter. Four hundred trials followed in five blocks of 80 experimental trials. *Catch* trials were presented on 20% of the total trials. Total trial number was doubled due to the additional SOA. Again, the experimenter monitored the participants' eyes throughout testing for central fixation.

The participants were randomly presented with either of two SOAs in a trial. Once they initiated the trial by pressing the space bar, the trials proceeded as follows. A display with the rectangle stimuli and fixation crosshair was presented for 1000 ms, followed by a 100-ms peripheral cue. A delay of 240 ms followed before targets were presented for 100 ms in trials with the short SOA. For long SOA trials, the 100-ms peripheral cue was followed by a 510-ms delay, a 100-ms central cue and a second 510-ms delay before targets were presented for 100-ms. The long SOA was selected to be near that of Experiment 1, which produced both space- and object-based inhibition.

Results

Orientation (+/−45°), SOA (340, 1220 ms) and Cueing (*cued*, *within*, *between*, *opposite*) were entered as within-subjects factors to an ANOVA of median RTs for correct trials (see Figure 3). Reaction times that were faster than 100 ms (M=0.7%) and slower than 1000 ms (M=0.2%) were excluded. False alarms (M=1.7%), misses (M=0.2%), or trials where eye movements were made (M=0.3%) were also removed.

Orientation—There was neither a main effect of Orientation nor an interaction with Cueing (F-values<1.0).

SOA—SOA produced a strong effect: participants responded 69 ms faster overall at the 1220-ms SOA than at the 340-ms SOA [$F(1,16)=52.2$, MSE=6129, $p<0.001$]. SOA interacted with Cueing [$F(3,48)=3.45$, MSE=394, $p<0.05$] (discussed below).

Cueing—A main effect of Cueing was found [$F(3,48)=71.2$, MSE=405, $p<0.001$] (see Figure 3). Space-based IOR was evident: *cued* RTs were 32 ms slower than *uncued* RTs [$t(16)=-10.15$, $p<0.001$]. Compared to each individual *uncued* condition, *cued* RTs were 31 ms slower than *within* RTs [$t(16)=-8.39$, $p<0.001$], 34 ms slower than *between* RTs [$t(16)=-10.0$, $p<0.001$] and 49 ms slower than *opposite* RTs [$t(16)=-12.3$, $p<0.001$]. Exploring the interaction between Cueing and SOA, we found that *cued* RTs were significantly different from each *uncued* mean RT at each SOA. Short SOA differences were as follows: *cued* RTs were 32 ms slower than *uncued* RTs [$t(16)=-6.23$, $p<0.001$] or, individually, 37 ms slower than *within* RTs [$t(16)=-6.26$, $p<0.001$], 28 ms slower than *between* RTs [$t(16)=-5.15$, $p<0.001$] and 49 ms slower than *opposite* RTs [$t(16)=-11.3$, $p<0.001$]. Space-based inhibition was found at the long SOA as well: *cued* RTs were 32 ms slower than *uncued* RTs [$t(16)=-8.64$, $p<0.001$] or, individually, 26 ms slower than *within* RTs [$t(16)=-7.02$, $p<0.001$], 39 ms slower than *between* RTs [$t(16)=-8.21$, $p<0.001$] and 50 ms slower than *opposite* RTs [$t(16)=-8.37$, $p<0.001$].

Collapsed over SOA, no evidence for object-based IOR was revealed [3 ms, $-1.0<t$-value<1.0]. However, based on the interaction between Cueing and SOA, we examined the effects separately for both SOAs. At the long SOA, *within* RTs were slower than *between* RTs by 14 ms [$t(16)=-3.38$, $p<0.01$]. This object-based IOR was consistent with that found in Experiment 1. Interestingly, at the short SOA, we found a trend for object-based facilitation: *within* RTs were faster than *between* RTs by 8 ms [$t(16)=1.88$, $p<0.10$].

Jordan and Tipper (1999) reported that object-based IOR diminished over the course of their experiment (18 to 8 ms comparing the first and second halves, although see Pratt & McAuliffe [1999] for contrary findings). Our use of two SOAs increased the number of trials that each participant experienced, which in turn may have affected the object-based effects we found. We therefore divided our data into first and second halves, and entered session half as another two-level factor in ANOVAs for space- and object-based effects separately.

Space-based inhibition did not reliably vary with experience [interactions between SOA, cueing (*cued* and *uncued*) and session half, all F-values ≤ 0.03, except a trend for an interaction between SOA and half: $F(1,16)=3.17$, MSE=408, $p=.09$]. However, object-based effects did vary with experience, but only at the short SOA, as reflected by a three-way interaction between SOA, cueing (*within* and *between*) and session half [$F(1,16)=4.78$, MSE=139, $p<0.05$]. At the long SOA, object-based IOR was present in both session halves [1^{st}: −13 ms, $t(16)=-2.74$, $p<0.05$; 2^{nd}: −10 ms, $t(16)=-2.56$, $p<0.05$]. At the short SOA, object-based facilitation was present in the 1^{st} half [13 ms, $t(16)=2.34$, $p<0.05$], but was absent in the second half [−2 ms, $-1.0<t$-value<1.0]. If anything, the increase in trial number decreased object-based facilitation at the short SOA.

Discussion

The current experiment revealed a very interesting profile of the time course of exogenous attention. Space-based IOR was found uniformly, regardless of SOA (32 ms at each SOA). However, object-based effects did change over time. The 8-ms trend was facilitatory at the 340-ms SOA whereas at the 1220-ms SOA, the reliable 14-ms effect was inhibitory. At the short SOA, the results are consistent with those of Schendel and Robertson (2000, submitted) and Schendel, Robertson and Treisman (2001), who found simultaneous object-based facilitation and space-based inhibition. The present results demonstrate that their findings were not necessarily due to the complexity of the displays used, but can generalize to simpler stimuli. At the long SOA, however, the results are consistent with those of Jordan and Tipper (1999), in which inhibition is found for both space and objects. Importantly, the present data demonstrate that space- and object-based IOR do not evolve over the same time course, at least as it relates to the simple stimuli used in many studies of object-based effects.

Experiment 3

The following three experiments were run to address a confound in the design of Experiment 2. In Experiment 2, we used two SOAs and found differences between object-based effects at the short and long SOAs. However, SOA was not the only difference between the two conditions; at the long SOA, participants were presented with a central cue whereas at the short SOA, they were not. Although space-based inhibition is present at both SOAs in Experiments 3 through 5, object-based effects become elusive, even at the long SOA. In Experiment 3, a back-to-center cue was omitted from both SOAs.

Methods

All methods are identical to the previous experiment, unless indicated otherwise.

Participants—Another seventeen University of California students participated for course credit. All reported normal or corrected-to-normal vision, right-handedness and gave informed consent.

Design—Participants were exposed to five trial types: *cued*, *within*, *between*, *opposite* and *catch* (when no target appeared). Each occurred with one of two stimulus onset asynchronies (SOAs): 340 or 1220 ms. All conditions were randomly intermixed.

Stimuli—Stimuli were identical to those used in the previous experiments, barring the central cue, which was not presented in this experiment.

Procedure—Participants completed 80 practice trials followed by five experimental blocks of 80 trials each, and were allowed brief breaks between blocks. The experimenter monitored the participants' central eye fixations through a camera and monitor, marking trials in which participants failed to maintain central fixation.

For each SOA, timing parameters were held constant for all trial types. Regardless of SOA, participants initiated the trial by pressing the space bar. The fixation and rectangles display appeared and remained alone on the screen for 1000 ms before a peripheral cue appeared for 100 ms. Timing parameters then differed depending on SOA. For the short SOA, after a 240-ms delay, a target appeared for 100 ms. Trials with a 1220-ms SOA continued after the peripheral cue as follows: a delay of 1120 ms elapsed before the target appeared for 100 ms. No target appeared on catch trials. Participants had 1000 ms to respond before the trial ended.

Results

In a within-subjects ANOVA, the factors of Orientation (+/− 45°), SOA (340, 1220 ms) and Cueing (*cued*, *within*, *between*, *opposite*) were entered (see Figure 4). Median correct response RTs were entered for each condition for each participant. Outliers below 100 ms (M=1.1%) and above 1000 ms were excluded (M=0.1%), as were false alarms (M=0.9%), misses (M=0.0%) and trials in which participants failed to maintain central eye fixation (M=0.6%).

Orientation—No main effect of Orientation was found [F-value<1.0]. A trend for an interaction with SOA was present [$F(1,16)=3.92$, MSE=165, $p<0.10$] (described below). Orientation did not interact with Cueing [F-value<1.0]. The three-way interaction did not reach significance [F-value=1.3].

SOA—There was a main effect of SOA: RTs were 26 ms faster at the short compared to the long SOA [$F(1,16)=16.0$, MSE=2836, $p=0.001$]. This is opposite what was found in Experiment 2. An extensive literature exists on foreperiod effects showing that, most frequently, longer SOAs result in decreased RTs (as in Experiment 2). However, when subjective expectancy of the target is varied, RT patterns can change (e.g., Drazin, 1961; for a review on foreperiod variables affecting simple RT, see Niemi & Näätanen, 1981). Comparing this to the last experiment, the lack of a central cue at the long SOA likely altered the expectations of the participants, thus resulting in relatively faster RTs at the short SOA and relatively slower RTs at the long SOA.

SOA did not interact with Cueing, also unlike Experiment 2. However, SOA did interact with Orientation: stimuli oriented −45° RTs were 31 ms slower at the long compared to the short

SOA [$t(16)=-4.59$, $p<0.001$], whereas RTs for stimuli oriented +45° were only 24 ms slower at the long compared to the short SOA [$t(16)=-3.36$, $p<0.01$].

Cueing—A main effect of Cueing was found [$F(3,48)=53.28$, MSE=436, $p<0.001$]. Space-based IOR was found: *cued* locations were inhibited relative to *uncued* conditions [31 ms, $t(16)=-8.55$, $p<0.001$] or, individually, relative to *within* [−30 ms, $t(16)=8.98$, $p<0.001$], *between* [−33 ms, $t(16)=7.46$, $p<0.001$] and *opposite* [−41 ms, $t(16)=8.90$, $p<0.001$] conditions.

Object-based effects were unreliable whether collapsed over SOA [−2 ms, $-1.0<t$-value<1.0] or not [short SOA: −1 ms and long SOA: −4 ms, $-1.0<t$-values<1.0].

Discussion

In the current experiment, removal of the central cue affected the pattern of results in two important ways. First, the RT advantage for long SOA trials was reversed into a RT advantage for short SOA trials. Without a central cue at the long SOA and/or a differentiation of the short and long SOAs, participants were unable to use the time beneficially for response preparation. Secondly, object-based effects were eliminated: at neither the short nor the long SOA were object-based effects detected. Importantly, however, space-based effects were unaffected by the removal of the central cue. Experiment 3 demonstrated a reliance of object-based effects on the presence of a central cue. Whether the central cue is critical to disambiguate short from long SOAs and/or necessary to reorient attention remains unclear, however.

Experiment 4

Because the central cue seemed essential in revealing object-based effects, in Experiment 4, we introduced a central cue for both the short (340 ms) and long (1253 ms) SOAs. In Experiment 4, the time between the peripheral and central cues was held constant (63 ms), with post-central cueing delays varying across SOA (63 ms and 976 ms), i.e. the time to reorient was varied. In this experiment, we expected to find both space- and object-based effects, without conflating central cueing and SOA duration (as in Experiment 2).

Methods

All methods are identical to the previous experiment, unless indicated otherwise.

Participants—Another seventeen University of California students volunteered or participated for course credit during summer sessions. All reported normal or corrected-to-normal vision, right-handedness and gave informed consent.

Design—Participants were again exposed to five trial types: *cued*, *within*, *between*, *opposite* and *catch* (when no target appeared). Each occurred with one of two stimulus onset asynchronies (SOAs): 340 or 1253 ms. All conditions were randomly intermixed.

Stimuli—The stimuli used were identical to those used in Experiments 1 and 2.

Procedure—As before, participants completed 80 practice trials before completing five blocks of 80 trials, separated by brief breaks. Eye fixation was monitored by the experimenter throughout testing.

Participants initiated the trial by pressing the space bar. The fixation crosshair and rectangles appeared and remained alone on the screen for 1000 ms before a peripheral cue appeared (for 112 ms). After a 63 ms delay, the central cue appeared for 102 ms. Timing parameters then differed depending on SOA. Trials with a 340-ms SOA continued as follows: 63 ms after central cue offset, a target appeared for 102 ms in one of four locations or not at all (*catch*). Trials with a 1253-ms SOA proceeded as follows after the central cue: a 976-ms delay elapsed before targets appeared for 102 ms in one of four locations or not at all (as above). Participants had 1000 ms to respond before the trial ended.

Results

Orientation (+/−45°), SOA (340, 1253 ms) and Cueing (*cued*, *within*, *between*, *opposite*) were entered as factors in a within-subjects ANOVA (see Figure 5). Correct median RTs were entered for each condition for each participant. Data from trials in which participants responded too early (<100 ms, *M*=1.0%), responded too late (>1000 ms, *M*=0.0%), made eye movements (*M*=2.1%), missed the target (*M*=1.6%) or made false alarms (*M*=2.7%) were excluded from analyses.

Orientation—Neither a main effect of Orientation, nor any two-way interactions with Orientation reached significance [all *F*-values<1.0]. The three-way interaction was non-significant [*F*(3,48)=1.86].

SOA—There was no main effect of SOA [*F*-value<1.0]. However, SOA did interact with Cueing (discussed below).

Cueing—A main effect of Cueing was present [*F*(3,48)=56.0, MSE=422, p<0.001], revealing space-based IOR. *Cued* RTs were slower than *uncued* RTs [31 ms, *t*(16)=−8.81, p<0.001] or, individually, *within* [−30 ms, *t*(16)=−7.10, p<0.001], *between* [−31 ms, *t*(16)=−8.39, p<0.001] and *opposite* RTs [−43 ms, *t*(16)=−9.74, p<0.001]. Cueing and SOA also interacted [*F*(3,48) =3.79, MSE=218, p<0.05]. At the short SOA, *cued* RTs were slower than *uncued* RTs [38 ms, *t*(16)=−8.39, p<0.001] or, individually, for *within* [−40 ms, *t*(16)=−8.14, p<0.001], *between* [−36 ms, *t*(16)=−7.75, p<0.001] and *opposite* RTs [−50 ms, *t*(16)=−9.51, p<0.001]. A similar pattern of space-based inhibition was found at the long SOA: c*ued* RTs were slower than *uncued* RTs [26 ms, *t*(16)=−6.84, p<0.001] or, individually, for *within* [−24 ms, *t*(16)=−6.18, p<0.001], *between* [−29 ms, *t*(16)=−5.95, p<0.001] and *opposite* RTs [−40 ms, *t*(16)=−7.73, p<0.001].

Object-based effects varied across SOA and were in the facilitatory direction at the short SOA [3 ms, *t*-value=1.04] but in the inhibitory direction at the long SOA [−4 ms, *t*-value=−1.08]. Object-based effects were not reliable at either SOA, or collapsed over SOA [1 ms, −1.0<*t*-value<1.0].

Because the nature of the Cueing by SOA interaction shown in Figure 5 was not completely explained by looking specifically at space- and object-based effects, it is possible that the *cued* condition primarily contributed to the interaction. In order to test this hypothesis, an ANOVA was performed in which the *cued* condition was removed[6]. The logic is that if the *cued* condition carries the interaction between Cueing and SOA, then the interaction should disappear when the condition is removed. The interaction did not reach significance under these conditions: *F*(2,32)=1.12, MSE=234, p=0.34. When the *within* condition was removed, the interaction was reduced to a non-significant trend [*F*(2,32)=2.89, MSE=236, p=0.07], but when either the *between* or *opposite* conditions were removed, the interaction remained reliable [*F*(2,32)=5.33, MSE=252, p=0.01 and *F*(2,32)=7.02, MSE=184, p<0.01, respectively]. When both the *cued* and *within* conditions were removed, the interaction disappeared completely [*F*-value<1.0]. These additional analyses reveal that the changes between SOA and cueing occured within the cued object, namely in the *cued* and *within* conditions.

[6]We thank an anonymous reviewer for this suggestion.

Discussion

A central cue was presented at both the short and long SOAs in Experiment 4, while maintaining the delay between peripheral and back-to-center cues fixed at 63 ms. Under these conditions, space-based IOR was present at both short and long SOAs. Conversely, object-based effects were absent at both SOAs. As in Experiment 2, although statistically unreliable in Experiment 4, object-based effects changed from facilitatory to inhibitory at short and long SOAs, respectively. Experiment 4 provides evidence that the absence of back-to-center cueing in Experiment 3 was not the sole reason for the absence of object-based effects.

Experiment 5

An alternative and complimentary approach, again using central cueing for both SOAs, was adopted in Experiment 5. Here, the delay between peripheral cue offset and central cue onset varied across SOA (63 ms and 976 ms), whereas the delay between central cueing offset and target onset was held constant (63 ms). In this manner, at the long SOA, the central cue presumably reoriented attention more immediately before target onset than in Experiment 4.

Methods

All methods are identical to the previous experiment, unless indicated otherwise.

Participants—Twenty University of California students participated for course credit. All reported normal or corrected-to-normal vision, right-handedness and gave informed consent. Three participants were excluded: one for failing to use the appropriate response device and two for high false alarm rates on catch trials (11 and 20%).

Design—*Cued*, *within*, *between*, *opposite* and *catch* (when no target appeared) trial types were presented randomly with one of two stimulus onset asynchronies (SOAs): 340 or 1253 ms.

Stimuli—Stimuli were identical to those used in all previous experiments.

Procedure—As in the other two-SOA experiments, 80 trials of practice preceded five 80-trial experimental blocks. Breaks were allowed between blocks. Eye movements were monitored by the experimenter throughout testing.

As before, participants initiated the trial by pressing the space bar. The display and fixation appeared centered on the screen for 1000 ms before a peripheral cue appeared (for 107 ms). Timing parameters then differed depending on SOA. For 340-ms SOA trials, a 63-ms delay elapsed after the peripheral cue, the central cue appeared for 107 ms, after a second 63-ms delay, a target appeared for 110 ms. For 1253-ms SOA trials, a 976-ms delay elapsed before the central cue appeared for 107 ms. A target appeared 63 ms after the central cue offset for 110 ms. On 20% of trials, no target appeared. Participants had 1000 ms to respond before the trial ended.

Results

Orientation (+/−45°), SOA (340, 1253 ms) and Cueing (*cued*, *within*, *between*, *opposite*) were entered into a 2×2×4 within-subjects ANOVA on correct median RTs (see Figure 6). Data from trials in which targets were missed (M=0.9%), eye movements (M=1.0%) or false alarms were made (M=3.5%) and trials on which targets were responded to anticipatorily (<100 ms, M=2.0%) or too slowly (>1000 ms, M=0.0%) were excluded.

Orientation—Orientation did not produce a main effect [$F(1,16)=1.03$, $p>0.10$]. Neither of the two-way interactions reached significance [both *F*-values<1.0], nor did the three-way interaction [$F(3,48)=1.69$, $p>0.10$].

SOA—Means of median RTs were not reliably different at the two SOAs [$F(1,16)=2.49$, $p>0.10$]. SOA did, however, interact with Cueing (discussed below).

Cueing—Cueing produced a main effect [$F(3,48)=24.1$, MSE=1307, $p<0.001$]: *cued* RTs were slower than *uncued* RTs [−36 ms, $t(16)=-5.78$, $p<0.001$] or, individually, slower than *within* RTs [−38 ms, $t(16)=-5.77$, $p<0.001$], *between* RTs [−35 ms, $t(16)=-5.21$, $p<0.001$] and *opposite* RTs [−47 ms, $t(16)=-6.16$, $p<0.001$]. Cueing interacted with SOA [$F(3,48)=6.94$, MSE=351, $p=0.001$]. Space-based inhibition was found at both SOAs: *cued* vs. *uncued* RTs [short SOA: −45 ms, $t(16)=-6.79$, $p<0.001$; long SOA: −27 ms, $t(16)=-3.25$, $p<0.01$] or, individually, for *within* RTs [short SOA: −46 ms, $t(16)=-6.34$, $p<0.001$; long SOA: −32 ms, $t(16)=-4.25$, $p=0.001$], *cued* vs. *between* RTs [short SOA: −44 ms, $t(16)=-6.50$, $p<0.001$; long SOA: −22 ms, $t(16)=-2.19$, $p<0.05$], and *cued* vs. *opposite* RTs [short SOA: −59 ms, $t(16)=-6.84$, $p<0.001$; long SOA: −34 ms, $t(16)=-3.76$, $p<0.01$].

Object-based effects were not detected when RTs were collapsed over SOA [2 ms, −1.0<*t*-value<1.0], or when analyzed separately for each SOA [short SOA: 2 ms, −1.0<*t*-value<1.0; long SOA: 9 ms, $t(16)=1.43$, $p>0.10$].

Again, as in Experiment 4, we conducted further analyses to explore the Cueing by SOA interaction: we repeated the ANOVA and removed the *cued*, *within*, *between* and *opposite* conditions individually. When the *cued* condition was removed, the interaction was non-significant: $F(2,32)=1.63$, MSE=246, $p>0.20$. When any of the other three cueing conditions were removed (*within*, *between* or *opposite*), the interaction was present [*F*-values>8.0, p-values<0.001]. In the case of the current experiment, the *cued* condition primarily carried the interaction. Because the *cued* condition is susceptible to both space- and object-based influences, the results are inconclusive as to which might be changing with SOA.

Discussion

In Experiment 5, as in Experiments 3 and 4, no object-based effects were found, whether at the short or long SOA. However, space-based IOR remained present, regardless of SOA or which uncued condition was compared against the cued condition. Pratt and Fisher (2002) similarly manipulated the presence of a central cue and inter-stimulus-interval between peripheral and central cues and the target to determine timing influences in the emergence of space-based IOR. They found space-based IOR was present across a broad range of SOAs (although it was weaker at SOAs ≤ 200 ms), with and without central cues. Their space-based results are consistent with ours. We have additionally shown, however, that object-based IOR is sensitive to those timing manipulations.

Overall Results

A mixed-factors ANOVA on both space- and object-based effects (within-subjects factors) across experiments (between-subjects factor) was performed for the long and short SOAs separately. We examined the space-based effects (*cued* vs. *uncued* RTs) and the object-based effects (*within* vs. *between* RTs) across all five experiments for the long SOA, but only for Experiments 2–5 for the short SOA (since only those latter experiments probed IOR at short SOAs).

Across all experiments, at the long SOA, an inhibitory 29-ms space-based effect was found [$F(1,80) = 116.2$, MSE = 308, $p < .001$] that did not interact with experiment [*F*-value<1.0], revealing its stability. There was also a main effect of experiment [$F(4,80)=2.65$, MSE=7380, $p<0.05$], reflecting changes in global reaction times across groups. At the long SOA, an inhibitory 6-ms object-based effect emerged, although it interacted with experiment [$F(1,80)=6.18$, MSE=221, $p<0.05$ and $F(4,80)=3.67$, MSE=221, $p<0.01$, respectively]. Here, the interaction reflects the instability of the object-based effects over the five experiments at the long SOA.

A parallel analysis of short SOAs was performed. A main effect of experiment was found [$F(3,64)=5.22$, MSE=5874, $p<0.01$]. An overall 38-ms inhibitory space-based effect was found [$F(1,64)=179.24$, MSE=269, $p<0.001$], which did not interact with experiment [*F*-value=1.0]. Again, space-based IOR was stable. The analysis of the object-based effects revealed only a trend [$F(1,64)=2.71$, MSE=132, $p=0.11$]. Notably, however, this was a 3-ms *facilitatory* object-based effect. Experiment showed a main effect [$F(3,64)=6.27$, MSE=5711, $p=0.001$], but did not interact with the object-based effect [*F*-value<1.0]. Across experiments, at the short SOA, performance was consistent with simultaneous and opposite effects of space- and object-based attentional selection.

General Discussion

Space-based IOR

In five experiments using spatially non-predictive, peripheral, exogenous cues, space-based IOR was consistently demonstrated at cued locations. Space-based inhibition was found regardless of SOA. This was true whether the effects were plotted against peripheral-cue-to-target SOA or against the most-recent-cue-to-target SOA (whether a peripheral or central cue). Figure 7 illustrates these two forms of plotting the data. To some, it may seem surprising that space-based IOR was demonstrated at all at the shortest SOAs given the findings of Posner and Cohen (1984) and others (e.g., Berger, Dori & Henik, 1999,Goldsmith & Yeari, 2003) who found facilitation using non-predictive exogenous cueing at short SOAs (under 200 ms). Other studies, however, have demonstrated IOR at even shorter SOAs (e.g., at 0-, 65- and 130-ms SOAs by Tassinari et al. [1994]—although see the debate between Lupianez & Weaver [1998] and Tassinari et al. [1998] regarding the findings with regard to 0-ms SOA). Importantly, for our purposes, space-based IOR was reliably observed in all experiments, regardless of minor changes in procedure (e.g., trial timing and back-to-center cueing, see Figure 7 and Table 1).

However, as discussed in the Introduction, our primary aim was to investigate whether (and under what conditions) the emergence of space-based IOR was accompanied by object-based IOR. A number of differences existed between studies in the literature that reported conflicting effects of object-based IOR, and we set out to examine which of those differences affected the nature and time course of object-based effects.

Object-based IOR

In Experiment 1, in which only a long SOA with central cueing was included, object-based IOR was observed, replicating Jordan and Tipper’s findings (1999). This effect was observed again in Experiment 2 when two SOAs were intermixed and a back-to-center cue was only present at the long SOA. Object-based IOR was only observed at the long SOAs (1176 ms in Experiment 1 and 1220 ms in Experiment 2). At the short SOA in Experiment 2, the object-based effect was facilitatory in direction, although it manifested only as a statistical trend ($p<0.10$). This result was quite intriguing for two reasons. First, object-based facilitation has most often been reported using predictive cues (e.g., Egly et al., 1994; Moore et al., 1998; Robertson & Kim, 1999), but here the trend is present under non-predictive cueing conditions. Second, the results from Experiment 2 support simultaneously present space-based inhibition and object-based facilitation. Although this may seem puzzling at first, it is consistent with two different specialized attentional systems. As mentioned earlier, arguments have been made that object- and space-based attention are both cognitively and neurologically separable (Berger & Henik, 2000; Berlucchi, Chelazzi & Tassinari, 2000; Collie, Maruff, Yucel, Dankert & Currie, 2000; Posner et al., 1985; Rafal & Robertson, 1996; Tipper et al., 1997). If these attentional mechanisms are operating separately but in parallel, finding opposite behavioral effects for each would be expected under the appropriate conditions, and the study reported here supports this prediction (see also Schendel et al., 2001; Schendel & Robertson, 2000; submitted).

In Experiments 3 through 5, which aimed to dissociate SOA from the presence and absence of back-to-center cueing, we failed to find any reliable object-based effects (whether inhibitory or facilitatory). Two evident possibilities exist, which are not mutually exclusive: in Experiment 2, the central cue may have disambiguated short from long SOA trials and/or the central cue may have reoriented attention away from the peripheral cue in long SOA trials. In all three latter experiments, the central cue *per se* could not be used to disambiguate short from long SOA trials (although in Experiments 4 and 5, its relative timing could). However, based on Experiments 3–5, the presence or absence of a central cue did not account for the direction, presence or absence of object-based effects. When participants were not given a disambiguating cue, their performance failed to reflect reliable object-based attentional orienting (whatever its direction).

One variable did separate out reliable object-based effects from the rest: the delay between the target and its immediately preceding (i.e., the most recent) cue (compare Figure 7A to 7B, in which data are plotted relative to the peripheral or most recent cue SOA, respectively). Across studies, whether peripheral or central, preceding cues within 400 ms of target presentation (see Figure 7B) elicited statistically unreliable object-based effects (all facilitatory, barring a 1-ms inhibitory effect in Experiment 3). Presumably, this reflects the necessary delay for attentional selection of the object. Cues preceding the target by approximately 600 ms elicited reliable object-based inhibition, which then disappeared by around 1000 ms. The overall pattern points to SOA between the target and the most recent preceding cue as a better determinant of the direction of object-based effects than the traditionally presented peripheral-cue-to-target SOA (note that space-based effects were not differentiated by cue type).

These findings provide further evidence for parallel but separate object- and space-based IOR by showing that they occur over a different time course and are differentially sensitive to exogenous visual cues: object-based IOR had a slow rise time and fast fall time compared to space-based IOR which had a fast rise time and was sustained as long an interval as was tested.

It is possible that under different conditions space-based IOR might become similarly fragile[7]. For instance, space-based IOR was initially elusive in discrimination tasks. However, in 1997, Lupiañez and colleagues reported space-based IOR in a discrimination task when SOAs were extended longer than had been commonly used with detection tasks. Another example is the demonstration that space-based IOR depends on back-to-center cues when using directional gaze-cues (Frischen and Tipper, in press). However, because the stimulus and design introduced by Egly, Driver and Rafal (1994) has had an enormous influence over the object-based literature, we contend that it is important to demonstrate the simultaneous fragility of object-based IOR in the presence of robust space-based IOR using the two-rectangle cueing approach.

[7]We thank Steve Tipper for drawing our attention to this issue.

In sum, the current set of five experiments explored space- and object-based IOR in a variety of conditions (see Table 1). We attempted to carefully match the various parameters of an influential study showing object-based IOR in static displays (Jordan & Tipper, 1999) to address conflicting answers to a question in the literature: does inhibition extend to objects as it does to space, and to what degree do they temporally overlap? We managed to replicate object-based IOR, although like others (e.g., Becker & Egeth, 2000;Muller & vonMuhlenen, 1996), we found it to be a non-trivial endeavor. In a two-rectangle display, object-based effects, when present in exogenous orienting designs, are slow to emerge, small in magnitude and susceptible to minor changes in procedure. In contrast, space-based IOR can occur relatively rapidly and its larger magnitude is consistent across a variety of cueing and timing manipulations (compare Figures 7A and B). This is consistent with a number of studies showing sustained space-based IOR (e.g., using simpler displays containing only two locations and without a central cue, Samuel and Kat [Experiment 3, 2003] found space-based IOR with a SOA of 1700 ms, as did Castel, et al. [2003] with SOAs of up to at least two seconds).

Relevance to Other Findings of Object-based IOR

In 1991, Tipper, Driver and Weaver reported the first formal test of object-based IOR. In these studies, two squares (i.e., objects) were presented on each side of a central fixation, one square was cued and then the whole display rotated followed by target presentation. Both objects moved to different locations, yet when the target appeared in the object that was cued, RTs were slower than when it appeared in the uncued object. Tipper and his colleagues went on to show that space-based IOR also persisted at the cued location: when the target was presented in the (now empty) cued location, RT was slower than when it appeared in uncued locations (Tipper, Jordan & Weaver, 1999). These results were taken as strong evidence for both object- and space-based components of IOR and were consistent with the idea that both types of IOR improved search efficiency.

Later studies demonstrated that this object-based effect could be described as a space-based effect within a spatial reference frame maintained through rigid rotation (Schendel & Robertson, 2000, submitted; Robertson, 2004). They carried out a study in which, to maximize their chances of detecting object-based IOR, they separated participants into those who did or did not show the expected object-based inhibitory effect demonstrated by Tipper and colleagues (1994). In those participants who showed object-based IOR when objects underwent rigid rotation together (i.e., conformed to the gestalt grouping principle of common fate), they found no evidence for object-based IOR when the objects moved to those same positions disjointedly (i.e., when the objects were not grouped). In other words, when the spatial relationship between the two objects was disrupted, object-based IOR was no longer present. Schendel and Robertson (2000, submitted) proposed that this disappearance of object-based IOR was due to attentional allocation to the cued *location* in a spatial reference frame that was maintained under conditions of smooth rotation, but was not maintained when the boxes moved independently. They claimed that the effect reflected space-based IOR, but in rotated coordinates. This argument can be applied to a number of studies that have used objects undergoing rigid rotation (e.g., Gibson & Egeth, 1994). In fact, Gibson and Egeth made a similar point: “IOR can operate on different kinds of locations—those that remained fixed with respect to an object and those that remain fixed with respect to the environment” (p.324).

Studies using static displays cannot be interpreted in the same manner, and some have argued that the inhibitory mechanisms engaged in static and dynamic displays are distinct (e.g., Christ et al., 2002). Investigations using static displays have supported the existence of object-based IOR, including those that motivated the present set of studies (Jordan & Tipper, 1998; 1999). In two reports using the two-rectangle paradigm (Reppa & Leek, 2003; Leek, Reppa & Tipper, 2003), the question of whether object-based IOR spreads within and between object parts was investigated by segmenting the rectangles. Interestingly, in both reports, RTs were faster within an object part as compared to shifts between object parts. These data show that targets within a part were *facilitated* by the cue, even at SOAs of 820 and 1220 ms. Two possible explanations are: the parts were not perceived as belonging to the same object (i.e., two distinct objects, creating a similar case as in the current Experiment 2 where object-based facilitation is weakly found in the presence of space-based IOR), or the abutting parts distorted the perceived space (an illusion described by Kanizsa [1979]; Robertson and Kim [1999] have demonstrated that illusions affecting perceived space can influence object-based facilitatory effects). These two studies corroborate the fickleness of object-based effects, at least in a non-predictive exogenous version the two-rectangle paradigm.

One other specific report of object-based IOR bears mention. Jordan and Tipper (1998) compared IOR in illusory objects versus undefined spatial locations (using an SOA of 1186 ms) and showed that the magnitude of inhibition was greater in the former. They compared IOR in two display types: when Pac-man type (Kanizsa) elements were configured to form illusory contours perceived as squares on each side of fixation versus a display in which the Pac-men were misoriented, producing no obvious illusory object. When illusory contours made illusory objects, greater IOR was present at the cued location than when they did not. While Jordan and Tipper argued that this demonstrated both object- and space-based IOR in illusory objects, illusory contours also make spatial locations more salient (illusory contours can affect perceived brightness and/or figural depth assignment [e.g. Dresp, 1992; Matthews & Welch, 1997]). Due to increased salience, the illusory figures may have provided a more effective location marker than the misoriented elements, increasing the strength of space-based IOR. Although this hypothesis has yet to be empirically tested, it does provide an alternate interpretation of the results. In this case, the illusory objects serve to reduce spatial uncertainty, and in doing so, induce more evident space-based IOR.

The function of IOR, as originally offered by Posner and Cohen (1984), was to inhibit return to a location where a target had not been detected, hence the nomenclature “inhibition of return.” This mechanism made selection more efficient by increasing the probability of sampling new locations when searching for a target. Later explanations invoked the intuitively appealing idea that objects themselves should play an influential role in IOR, because objects are what are sought (e.g., Tipper et al., 1991). To the extent that IOR increases efficiency in visual search, object-based IOR appears to play only a subsidiary role, whereas space-based IOR is robust, consistent and reliable[8].

Objects clearly do facilitate attentional selection. Results similar to those of Egly and his colleagues’ (1994) original findings of object-based facilitation have been replicated many times, and their method has become almost a paradigm case with which to study object- versus space-based attention. However, the role of IOR in inhibiting return to objects that have already been selected and rejected is less certain than for spatial locations. In the present set of studies, we have shown that the facilitatory and inhibitory directions of object-based effects can vary under conditions over which space-based inhibition remains stable. We argue that space-based IOR plays a much stronger role in the inhibitory mechanisms that affect search efficiency.

Acknowledgements

This research was funded by NIH Grant #MH55682 to the second author. We thank Joy Mirjahangir, Kathryn Clark, Ashley Barks and David Zlotnick for their valuable assistance with data collection. We also thank Krista Schendel for many helpful discussions.

[8]The same argument might be applied to facilitatory components of attention (if object-based effects are weaker and less stable than space-based effects), although those are not under direct investigation in this report.

References

Abrams RA, Law MB. Object-based visual attention with endogenous orienting. Perception & Psychophysics 2000;62(4):818–833. [PubMed: 10883587]

Becker L, Egeth H. Mixed reference frames for dynamic inhibition of return. Journal of Experimental Psychology: Human Perception & Performance 2000;26(3):1167–1177. [PubMed: 10884015]

Behrmann M, Tipper SP. Attention accesses multiple reference frames: Evidence from visual neglect. Journal of Experimental Psychology: Human Perception & Performance 1999;25(1):83–101. [PubMed: 10069027]

Berger A, Dori H, Henik A. Peripheral non-informative cues do induce early facilitation of target detection. European Journal of Cognitive Psychology 1999;11(1):119–137.

Berger A, Henik A. The endogenous modulation of IOR is nasal-temporal asymmetric. Journal of Cognitive Neuroscience 2000;12:421–428. [PubMed: 10931769]

Berlucchi G, Chelazzi L, Tassinari G. Volitional covert orienting to a peripheral cue does not suppress cue-induced inhibition of return. Journal of Cognitive Neuroscience 2000;12(4):648–663. [PubMed: 10936917]

Castel AD, Chasteen AL, Scialfa CT, Pratt J. Adult age differences in the time course of inhibition of return. Journal of Gerontology: Psychological Sciences 2003;58B(5):256–259.

Christ SE, McCrae CS, Abrams RA. Inhibition of return in static and dynamic displays. Psychonomic Bulletin & Review 2002;9:80–85. [PubMed: 12026955]

Collie A, Maruff P, Yucel M, Danckert J, Currie J. Spatiotemporal distribution of facilitation and inhibition of return arising from the reflexive orienting of covert attention. Journal of Experimental Psychology: Human Perception & Performance 2000;26(6):1733–1745. [PubMed: 11129370]

Danckert J, Maruff P, Crowe S, Currie J. Inhibitory processes in covert orienting in patients with Alzheimer's disease. Neuropsychology 1998;12(2):225–241. [PubMed: 9556769]

Danziger S, Kingstone A, Snyder JJ. Inhibition of return to successively stimulated locations in a sequential visual search paradigm. Journal of Experimental Psychology: Human Perception & Performance 1998;24(5):1467–1475. [PubMed: 9778832]

Drazin DH. Effects of foreperiod, foreperiod variability, and probability of stimulus occurrence on simple reaction time. Journal of Experimental Psychology 1961;62:43–50. [PubMed: 13724295]

Dresp B. Local brightness mechanisms sketch out surfaces but do not fill them in: psychophysical evidence in the Kanizsa square. Perception & Psychophysics 1992;52:562–570. [PubMed: 1437489]

Duncan J. Selective attention and the organization of visual information. Journal of Experimental Psychology: General 1984;113(4):501–517. [PubMed: 6240521]

Egly R, Driver J, Rafal RD. Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. Journal of Experimental Psychology: General 1994;123(2):161–177. [PubMed: 8014611]

Frischen A, Smilek D, Eastwood JD, Tipper SP. Inhibition of return in response to gaze cues: The roles of time-course and fixation cue. Perception & Psychophysics. in press

Gibson BS, Egeth H. Inhibition of return to object-based and environment-based locations. Perception & Psychophysics 1994;55(3):323–339. [PubMed: 8036113]

Goldsmith M, Yeari M. Modulation of object-based attention by spatial focus under endogenous and exogenous orienting. Journal of Experimental Psychology: Human Perception & Performance 2003;29(5):897–918. [PubMed: 14585013]

Jordan H, Tipper SP. Object-based inhibition of return in static displays. Psychonomic Bulletin & Review 1998;5(3):504–509.

Jordan H, Tipper SP. Spread of inhibition across an object's surface. British Journal of Psychology 1999;90(4):495–507.

Kanizsa, G. Organization in vision: essays on gestalt perception. New York: Praeger; 1979.

Klein RM. Inhibitory tagging system facilitates visual search. Nature 1988;334(6181):430–431. [PubMed: 3405288]

Klein RM. Inhibition of return. Trends in Cognitive Sciences 2000;4(4):138–147. [PubMed: 10740278]

Leek EC, Reppa I, Tipper SP. Inhibition of return for objects and locations in static displays. Perception & Psychophysics 2003;65(3):388–395. [PubMed: 12785069]

Lupiañez J, Milan EG, Tornay FJ, Madrid E, Tudela P. Does IOR occur in discrimination tasks? Yes, it does, but later. Perception & Psychophysics 1997;59(8):1241–1254. [PubMed: 9401458]

Lupiañez J, Weaver B. On the time course of exogenous cueing effects: a commentary on Tassinari et al. (1994). Vision Research 1998;38:1619–1621.

Macquistan AD. Object-based allocation of visual attention in response to exogenous, but not endogenous, spatial precues. Psychonomic Bulletin & Review 1997;4(4):512–515.

Matthews N, Welch L. The effect of inducer polarity and contrast on the perception of illusory figures. Perception 1997;26:1431–1443. [PubMed: 9616472]

Moore CM, Fulton C. The spread of attention to hidden portions of occluded surfaces. Psychonomic Bulletin & Review 2005;12(2):301–306. [PubMed: 16082810]

Moore CM, Yantis S, Vaughan B. Object-based visual selection: Evidence from perceptual completion. Psychological Science 1998;9(2):104–110.

Muller HJ, vonMuhlenen A. Attentional tracking and inhibition of return in dynamic displays. Perception & Psychophysics 1996;58:224–249. [PubMed: 8838166]

Niemi P, Naatanen R. Foreperiod and simple reaction time. Psychological Bulletin 1981;89:133–162.

Posner MI. Orienting of attention. Quarterly Journal of Experimental Psychology 1980;32(1):3–15. [PubMed: 7367577]

Posner, MI.; Cohen, Y. Components of visual orienting. In: Bouma, H.; Bouwhuis, DG., editors. Attention and Performance X: Control of Language Processes. X. London: Lawrence Erlbaum; 1984. p. 531-556.

Posner MI, Rafal R, Choate LS, Vaughan J. Inhibition of return: neural basis and function. Cognitive Neuropsychology 1985;2:211–228.

Pratt J, Fischer MH. Examining the role of the fixation cue in inhibition of return. Canadian Journal of Experimental Psychology 2002;56(4):294–301. [PubMed: 12491653]

Pratt J, McAuliffe J. Examining the effect of practice on inhibition of return in static displays. Perception & Psychophysics 1999;61(4):756–765. [PubMed: 10370341]

Pratt J, Sekuler AB. The effects of occlusion and past experience on the allocation of object-based attention. Psychonomic Bulletin & Review 2001;8:721–727. [PubMed: 11848591]

Rafal, RD.; Henik, A. The neurology of inhibition: Integrating controlled and automatic processes. In: Dagenbach, D.; Carr, TH., editors. Inhibitory processes in attention, memory, and language. San Diego, CA: Academic Press, Inc; 1994. p. 1-51.

Rafal, R.; Robertson, LC. The neurology of visual attention. In: Gazzaniga, MS., editor. The Cognitive Neurosciences. Cambridge, MA: MIT Press; 1996. p. 625-648.

Reppa I, Leek EC. The modulation of inhibition of return by object-internal structure: Implications for theories of object-based attentional selection. Psychonomic Bulletin & Review 2003;20(2):493–502. [PubMed: 12921430]

Robertson, LC. Essays in Cognitive Science. New York, NY: Psychology Press; 2004. Space, Objects, Minds and Brains.

Robertson LC, Kim MS. Effects of perceived space on spatial attention. Psychological Science 1999;10 (1):76–79.

Samuel AG, Kat D. Inhibition of return: A graphical meta-analysis of its time course and an empirical test of its temporal and spatial properties. Psychonomic Bulletin & Review 2003;10(4):897–906. [PubMed: 15000537]

Sapir A, Soroker N, Berger A, Henik A. Inhibition of return in spatial attention: Direct evidence for collicular generation. Nature Neuroscience 1999;2(12):1053–1054.

Schendel, KL.; Robertson, LC. Spatial reference frames in object-based attention. 2000, November; Poster presented at the 41st Annual Meeting of the Psychonomic Society; New Orleans, LA.

Schendel KL, Robertson LC. Object-based IOR may rely on updated spatial reference frames: A closer look at dynamic stimulus displays. submitted

Schendel KL, Robertson LC, Treisman A. Objects and their locations in exogenous cueing. Perception & Psychophysics 2001;63(4):577–594. [PubMed: 11436731]

Tassinari G, Aglioti S, Chelazzi L, Peru A, Berlucchi G. Do peripheral non-informative cues induce early facilitation of target detection? Vision Research 1994;34(2):179–189. [PubMed: 8116277]

Tassinari G, Aglioti S, Chelazzi L, Peru A, Berlucchi G. On the time course of exogenous cueing effects: a response to Lupianez & Weaver. Vision Research 1998;38:1625–1628.

Tipper SP, Driver J, Weaver B. Object-centred inhibition of return of visual attention. Quarterly Journal of Experimental Psychology A, Human Experimental Psychology 1991;43(2):289–298.

Tipper SP, Jordan H, Weaver B. Scene-based and object-centered inhibition of return: evidence for dual orienting mechanisms. Perception & Psychophysics 1999;61(1):50–60. [PubMed: 10070199]

Tipper SP, Weaver B, Jerreat LM, Burak AL. Object-based and environment-based inhibition of return of visual attention. Journal of Experimental Psychology: Human Perception & Performance 1994;20 (3):478–499. [PubMed: 8027711]

Tipper SP, Weaver B, Rafal R, Staarveldt Y, Ro T, Egly R, Danziger S, Reuter-Lorenz PA. Object-based facilitation and inhibition from visual orienting in the human split-brain. Journal of Experimental Psychology: Human Perception & Performance 1997;23(5):1522–1532. [PubMed: 9336963]

Vecera SP. Grouped locations and object-based attention: Comment on Egly, Driver, and Rafal (1994). Journal of Experimental Psychology: General 1994;123(3):316–320.

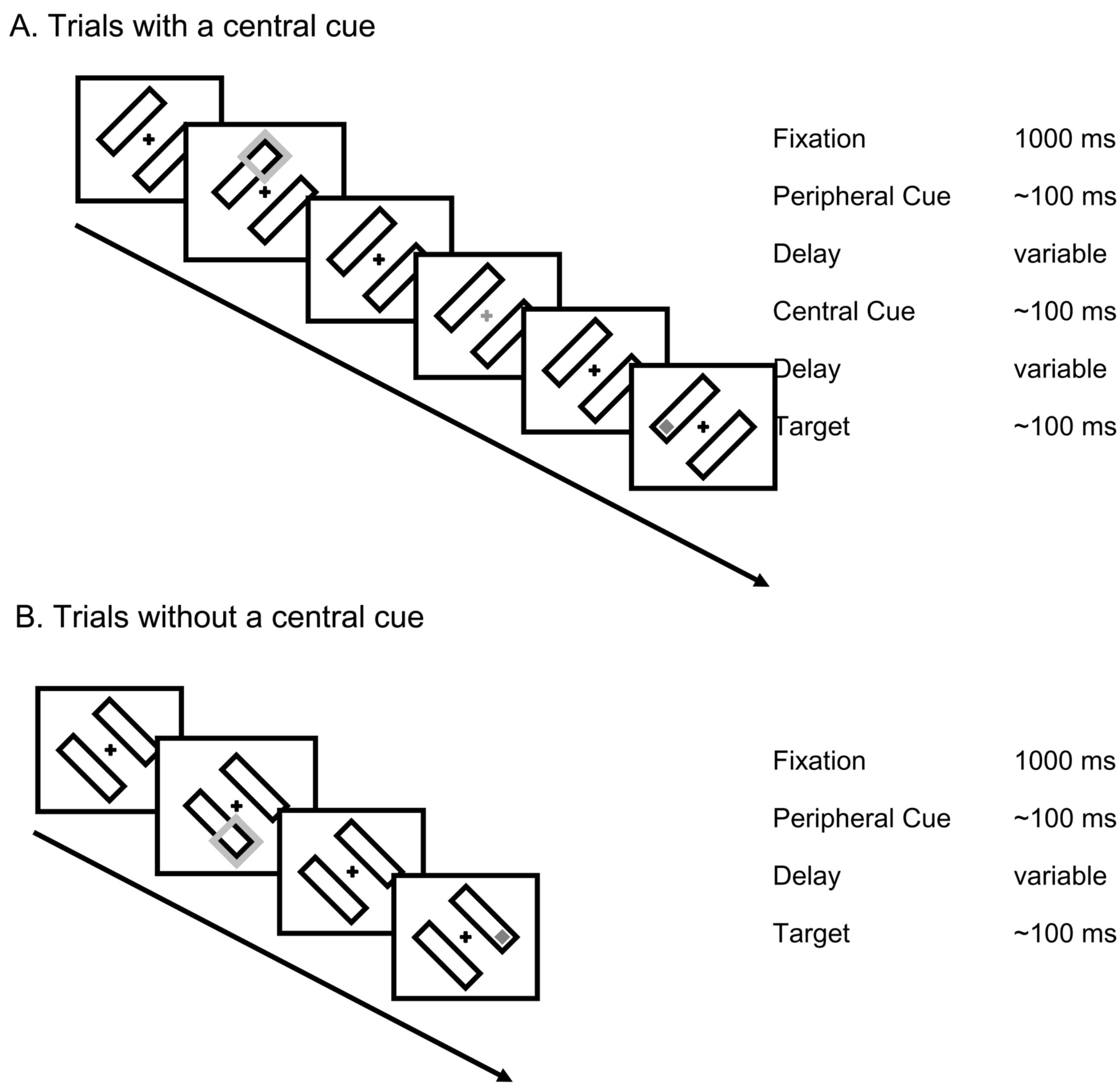

Figure 1.

The trial structure for trials with a central cue (A) and those without a central cue (B). Cues and targets appeared equiprobably at each of the two ends of the two rectangles. On 20% of trials, no target appeared (*catch*). On remaining trials, each condition (*cued*, *within*, *between* and *opposite*) was presented with equal likelihood (p=0.2). In (A), a *within* trial is illustrated, whereas in (B), a *between* trial is illustrated. Note that the distance between the cue and target is equal for *within* and *between* conditions. See individual experiment method sections for trial timing details.

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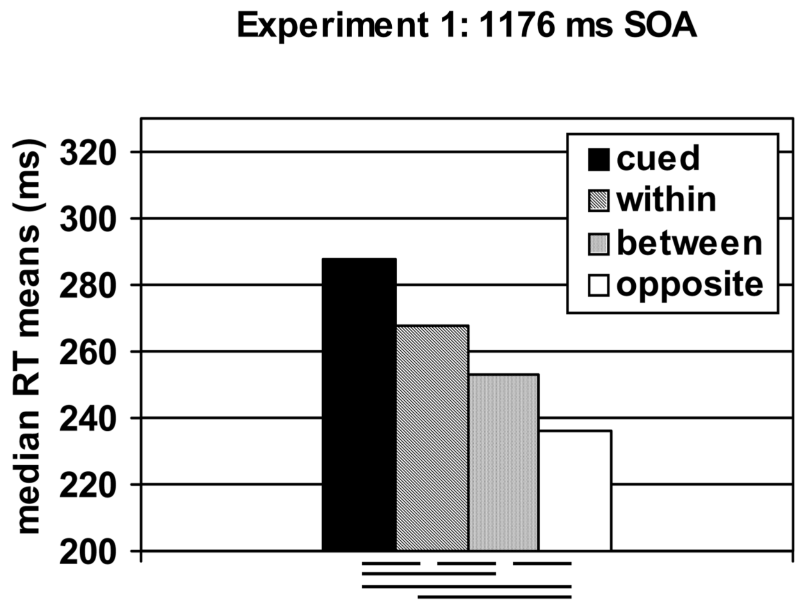

Figure 2.
Mean median reaction times are shown for each Cueing condition of Experiment 1. A central cue was present for all trials. Bars indicate significant differences ($p \leq .05$).

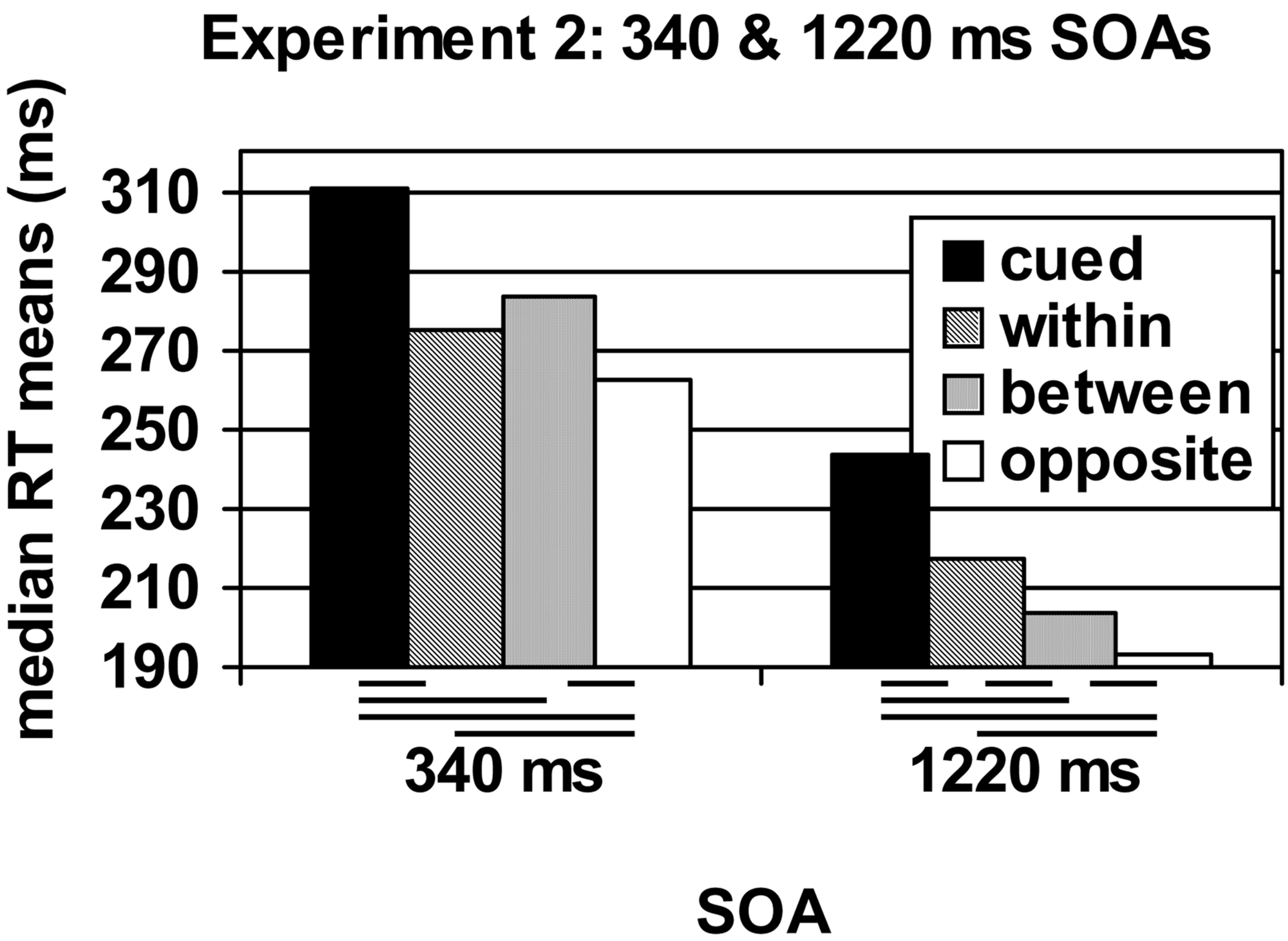

Figure 3.

Mean median reaction times are shown for each condition in the two (SOA) by four (Cueing) design of Experiment 2. A central cue was only presented at the longer SOA. Bars indicate significant differences ($p \leq .05$).

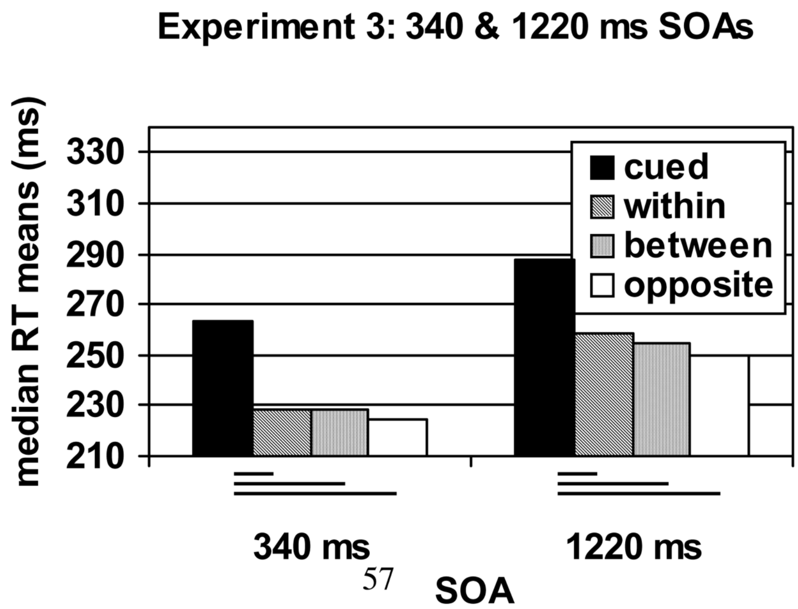

Figure 4.
Mean median reaction times are shown for each condition in the two (SOA) by four (Cueing) design of Experiment 3, in which no central cueing was present (at either SOA). Bars indicate significant differences ($p \leq .05$).

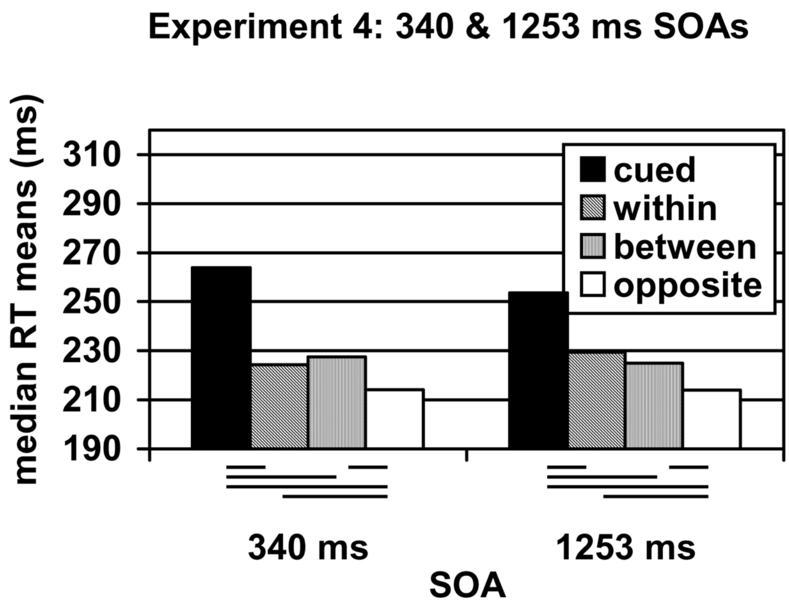

Figure 5.
Mean median reaction times are shown for each condition in the two (SOA) by four (Cueing) design of Experiment 4, in which the delay between peripheral cue offset and central cue onset was held constant over SOA (63 ms). Bars indicate significant differences ($p \leq .05$).

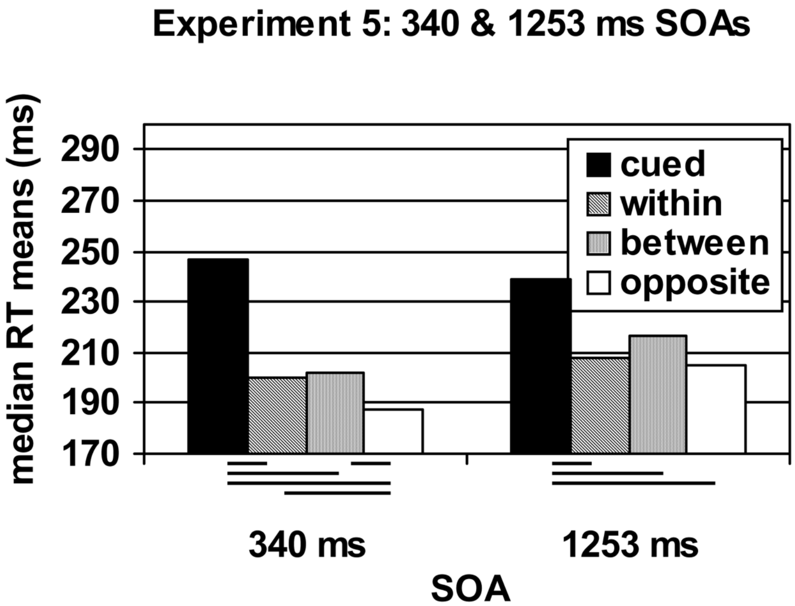

Figure 6.
Mean median reaction times are shown for each condition in the two (SOA) by four (Cueing) design of Experiment 5, in which the delay between central cue offset and target onset was held constant over SOA (63 ms). Bars indicate significant differences ($p \leq .05$).

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Figure 7A

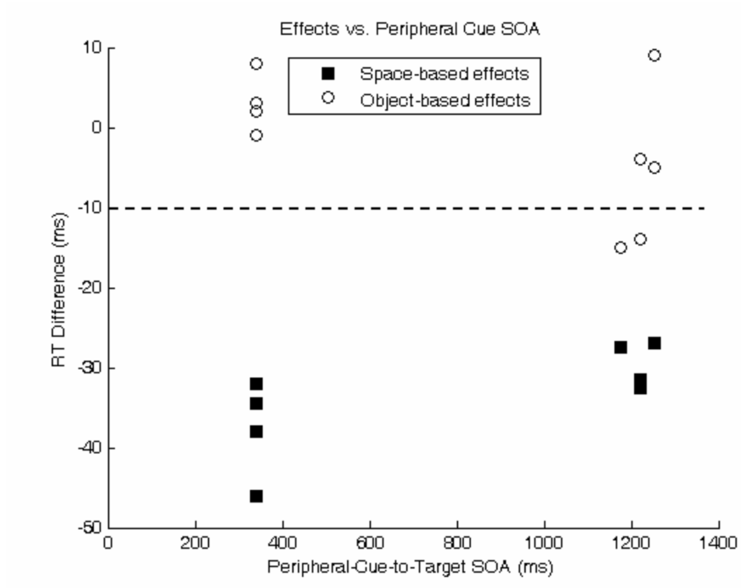

Figure 7B

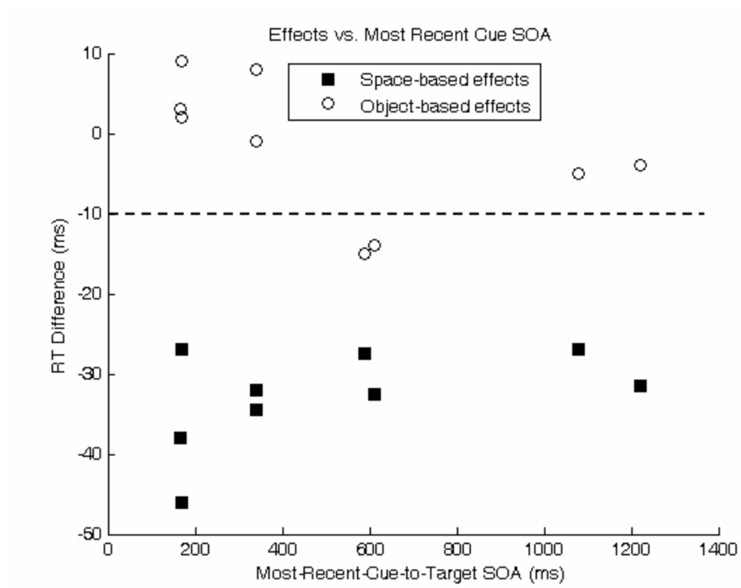

Figure 7.

Space-based effects (*uncued* minus *cued* RTs, filled squared) and object-based effects (*between* minus *within* RTs, open circles) are shown for Experiments 1 through 5. Negative values indicate IOR, whereas positive values indicate facilitation. *A.* Differences in means of medians are displayed for all experiments and peripheral-cue-to-target SOA. *B.* Differences in means of medians are displayed for all experiments and most-recent-cue-to-target SOA, whether central or peripheral. All data points below the dotted line indicate reliable inhibitory difference values ($p \leq .05$). None of the facilitatory differences reached significance.

Table 1

Experiment Parameters

	Peripheral-cue-to- target SOA (ms)	Most recent-cue-to-target SOA (ms)	Back-to-center cueing	Number of Participants Showing Effect	
				Space-based IOR	Object-based IOR
Jordan & Tipper (1999) *outline*	1166	583	Yes	N/A	N/A
Experiment 1	1176	588	Yes	14/17	14/17
Experiment 2	340	340	No	14/17	6/17
	1220	610	Yes	16/17	15/17
Experiment 3	340	340	No	16/17	10/17
	1220	1220	No	16/17	10/17
Experiment 4	340	165	Yes	16/17	7/17
	1253	1078	Yes	15/17	5/17
Experiment 5	340	170	Yes	17/17	6/17
	1253	170	Yes	15/17	11/17