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Inhibition of return: A graphical meta-analysis of its time course and an empirical test of its temporal and spatial properties

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Immediately after a stimulus appears in the visual field, there is often a short period of facilitated processing of stimuli at or near this location. This period is followed by one in which processing is impaired, rather than facilitated. This impairment has been termed *inhibition of return* (IOR). In the present study, the time course of this phenomenon was examined in two ways. (1) A graphical meta-analysis plotted the size of the effect as a function of the stimulus onset asynchrony (SOA) of the two stimuli. This analysis showed that IOR is impressively stable for SOAs of 300–1,600 msec. It also showed that the literature does not provide any clear sense of the duration of IOR. (2) An empirical approach was, therefore, taken to fill this gap in our knowledge of IOR. In three experiments, IOR was tested using SOAs between 600 and 4,200 msec. IOR was robust for approximately 3 sec and appeared to taper off after this point; the observed duration varied somewhat as a function of the testing conditions. In addition, for the first second, the degree of inhibition was inversely related to distance of the target from the original stimulus, but for the next 2 sec this spatial distribution was not observed. Theories of the mechanisms and function of IOR must conform to these spatial and temporal properties.

The visual complexity of the world around us, coupled with our finite processing capacity, results in moment-by-moment changes in the priority given to locations and objects in the visual field. In a series of papers, Posner and his colleagues (Posner, 1980; Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985) described some of the fundamental principles governing this attentional priority. The focus of the present paper is a type of negative priority first reported by Posner and Cohen: About 300 msec after the occurrence of a salient peripheral stimulus, perceptual processing of another stimulus in the same location is impaired. Posner et al. (1985) called this effect *inhibition of return* (IOR)—there is a reduced perceptual priority for information in a region that recently enjoyed a higher priority. A number of authors (e.g., Klein, 1988; Klein & MacInnes, 1999; Posner & Cohen, 1984) have suggested that an attentional priority system of this sort would enhance an organism's ability to search the visual environment by reducing the tendency to repeatedly sample a particular location.

The initial demonstrations of IOR involved simple detection tasks with simple visual displays. A typical experiment would have an initial display with two boxes, one on each side of a fixation point. The salient initial peripheral event (the *cue*) could be either a brief change in one of the boxes (e.g., the outline might brighten) or a brief presentation of a stimulus within one of the boxes. The subject's task would be to hit a button as soon as the *target* appeared, with the target typically being a small figure (e.g., an asterisk) appearing in one of the boxes. Under these conditions (e.g., Posner & Cohen, 1984), targets occurring in the cued location initially enjoy an advantage over targets in the uncued box. However, beginning at a cue–target stimulus onset asynchrony (SOA) of approximately 300 msec, the pattern reverses, with targets in the cued location now being responded to more slowly.

In the years following Posner's seminal work, scores of studies of IOR have been reported. Some of the major questions addressed in these studies have been the following. (1) Is the inhibition grounded in mechanisms that control eye movements (e.g., Abrams & Dobkin, 1994; Kingstone & Pratt, 1999; Klein, 2000; Posner et al., 1985; Rafal, Calabresi, Brennan, & Sciolto, 1989; Taylor & Klein, 2000)? (2) Is IOR attached to locations or to objects (e.g., Abrams, Christ, & Smith, 1999; Gibson & Egeth, 1994; Jordan & Tipper, 1998; Tipper, Driver, & Weaver, 1991; Tipper, Weaver, Jerreat, & Burak, 1994)? (3) Does IOR occur for discrimination as well as for detection tasks (e.g., Cheal, Chastain, & Lyon, 1998; Lupiáñez, Milan, Tornay, Madrid, & Tudela, 1997; Pratt & Abrams, 1999; Pratt, Kingstone, & Khoe, 1997)? (4) Does the strength of IOR diminish smoothly as a function of distance from the cued location (e.g., Bennett & Pratt, 2001; Maylor & Hockey, 1985; Pratt,

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Adams, & McAuliffe, 1998; Pratt, Spalek, & Bradshaw, 1999; Samuel & Weiner, 2001; Snyder, Schmidt, & Kingstone, 2001)?

In the present study, we sought to clarify the time course of IOR, using meta-analytic and empirical methods. Our first approach was to draw upon the substantial IOR literature, looking for regularities in when IOR begins and when it ends. This analysis can constrain theories of the mechanisms and purpose of IOR and can help to put new findings in an appropriate perspective. In fact, we undertook this time course analysis in order to help interpret results in our own lab that were based on inhibition following object disappearances, rather than object appearances (Samuel & Weiner, 2001). By knowing what the temporal and spatial properties of IOR are, researchers can determine whether observations made under new conditions are best interpreted in terms of the existing IOR literature or whether different mechanisms should be postulated.

Many studies have varied the cue–target SOA and, therefore, have provided some time course information. Our first approach differed from most prior studies in that it was based on a very large body of data, data coming from over 150 different conditions. We tapped the IOR literature to conduct a graphical meta-analysis. Our meta-analysis has much in common with a literature summary that Collie, Maruff, Yucel, Danckert, and Currie (2000, Table 1) recently published. We believe that our graphical presentation is in a format that will be quite useful to many researchers.

As a result of having conducted this graphical meta-analysis, we became aware of an important gap in the field's understanding of the time course of IOR: Despite scores of papers, with hundreds of conditions, the literature does not provide a clear sense of the duration of IOR. This led us to the second approach of the present study, which was to collect new empirical findings that would fill this gap in our knowledge. In doing so, we also examined the spatial distribution of the inhibitory effect and how this changes over time.

THE GRAPHICAL META-ANALYSIS

To specify the time course of IOR, we decided that using at least a hundred data points would provide an accurate approximation to the true time course, with each data point representing the results of one condition in an IOR experiment (see below). We selected the most common testing procedure for such experiments: The conditions included involved target detection following a cue, with a timed manual response (see Klein, 2000, for a graph of data from saccadic responses, rather than manual ones; see Lupiáñez et al., 1997, for a graph comparing detection cases with those for discrimination). Each point in the resulting graph represents the response time difference between responses to targets occurring at an uncued location and those to targets occurring in the location of the initial cue, at a given cue–target SOA. We ultimately plotted 166 such points, drawn from 27 papers. This is, of course, not an exhaustive analysis of the literature but is clearly a very large sample, large enough that it should represent the population means relatively well.

We can profitably examine the time course function in terms of its beginning, middle, and end. The beginning section, which we define as SOAs under 200 msec, has been the subject of two related controversies: Is facilitation consistently found, and must IOR be preceded by an initial facilitation? The graphical meta-analysis provides a visual answer to the first question: Most of the points are in the positive range, indicating that the facilitation effect is reasonably robust. However, a nontrivial number of points are near zero or even negative. Several recent papers have discussed possible reasons for the disparate results for short SOAs (e.g., Lupiáñez & Weaver, 1998; Pratt, Hillis, & Gold, 2001; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1998). If the many conditions contributing to Figure 1 are examined, it is generally the case that facilitation is found when the initial cue should be good at rapidly attracting attention (e.g., large, bright, long duration, relatively central, constrained possible locations); inhibition or no effect is more likely for less effective cues (smaller, dimmer, shorter, more peripheral, unconstrained possible locations). In addition, the figure shows that facilitation is most robust for the shortest SOAs (under 100 msec) and becomes less reliable as the SOAs reach the 200-msec range.

Perhaps the most striking feature of Figure 1 is the remarkable stability of IOR for SOAs of 300–1,600 msec. When the sample size is substantial, as it is for the points in the bottom panel of Figure 1, IOR is impressively constant in this range. The near-constant effect of about 25 msec is even more impressive, given the wide range of testing conditions, subjects, and laboratories contributing to this graph. This analysis makes it clear that IOR is a very stable phenomenon in this time range.

After we constructed Figure 1, it became obvious that the literature does not provide any clear sense of when IOR ends (perhaps accounting for the common statement in papers that "IOR lasts at least 1,000–1,500 msec"). Our graphical meta-analysis confirms that IOR is robust for at least 1,600 msec, but beyond that, there simply are not enough data available to state when it ends. The figure suggests that IOR may dissipate approximately 3 sec after the initial cue, but this estimate is based only on one condition from one study.

We have, therefore, collected data specifically intended to determine when IOR ends. We also included an examination of the spatial distribution of IOR and how it may evolve over time. The spatial distribution has been an important factor in recent debates about the basis of IOR (e.g., Pratt et al.'s, 1999, suggestion of attentional momentum and Snyder et al.'s, 2001, rejection of this position). In the first two experiments, we used the type of displays and procedures used by Samuel and Weiner (2001), but longer SOAs were used to look for the ending time for IOR. These displays have produced very robust IOR effects in our prior work. Experiment 3 pro-

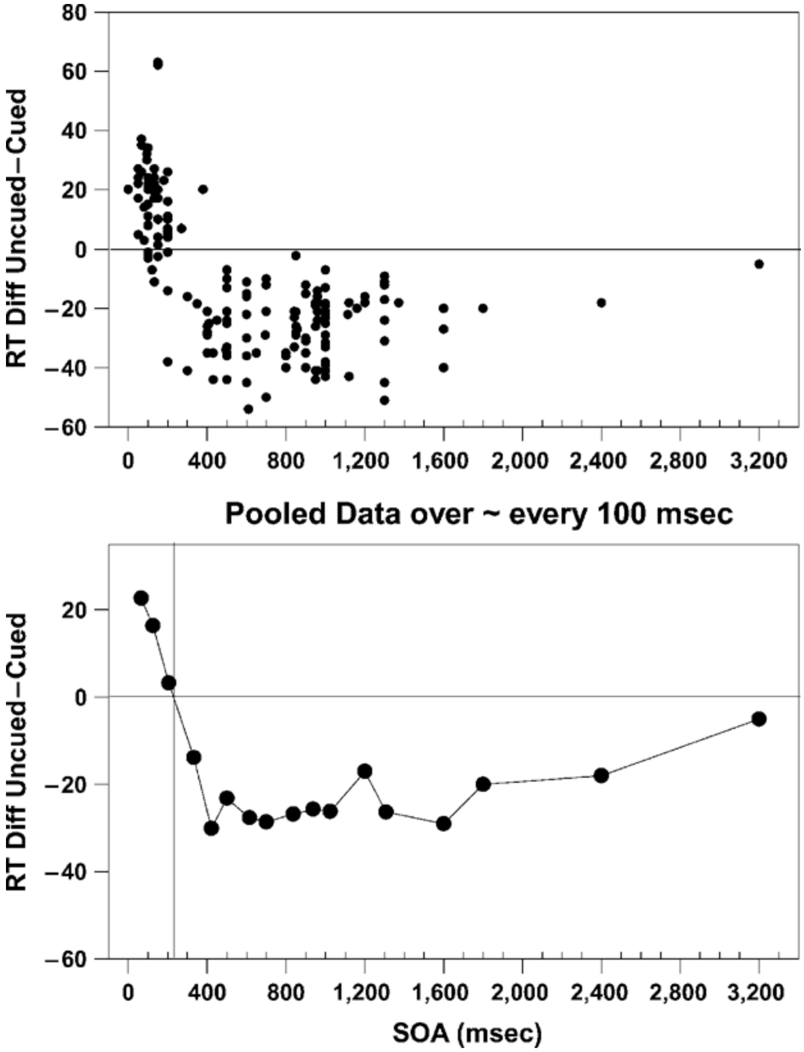


Figure 1. Top panel: difference in target detection reaction times for cued and uncued locations. Data are drawn from the following studies: Abrams & Dobkin (1994), Briand, Larrison, & Sereno (2000), Collie, Maruff, Yucel, Danckert, & Currie (2000), Danziger & Kingstone (1999), Danziger, Kingstone, & Snyder (1998), Folk, Remington, & Johnston (1992), Jordan & Tipper (1998), Kingstone & Pratt (1999), Lupiáñez, Milan, Tornay, Madrid, & Tudela (1997), Maruff, Yucel, Danckert, Stuart, & Currie (1999), Maylor & Hockey (1985), McDonald, Ward, & Kiehl (1999), Oonk & Abrams (1998), Posner & Cohen (1984), Pratt (1995), Pratt & Abrams (1999), Pratt, Adams, & McAuliffe (1998), Pratt, Hillis, & Gold (2001), Pratt, Spalek, & Bradshaw (1999), Reuter-Lorenz, Jha, & Rosenquist (1996), Riggio, Bello, & Umiltà (1998), Samuel & Weiner (2001), Tassinari & Berlucchi (1993), Taylor & Klein (2000), Tipper, Driver, & Weaver (1991), Tipper, Weaver, Jerreat, & Burak (1994), and Tipper, Weaver, & Watson (1995). Bottom panel: average difference scores, collapsing the data from the top panel, using a bin size of 100 msec.

vided a converging test, using even longer SOAs and simpler displays that are similar to those used in the majority of previous experiments.

EXPERIMENT 1

Experiment 1 was a direct extension of Samuel and Weiner's (2001) study. In that study, IOR was tested with SOAs ranging from 80 to 610 msec. The SOAs in Experiment 1 began where that study left off and extended the range up to 3 sec.

Method

Subjects. Forty-nine SUNY, Stony Brook students received course credit for participating. All had normal or corrected-to-normal vision. From 1 to 3 subjects were tested at a time. When multiple subjects were tested simultaneously, each faced a different wall in the testing booth, and each wore headphones presenting white noise that prevented any subject from hearing the sound of another's buttonpress.

Apparatus and Procedure. Displays were presented on Viewsonic 17-in. PT775 monitors, running at 100 Hz. The monitors were driven by a Matrox G400 video card. Each frame of each display was stored as a 480 × 640 point bitmap in the card's video memory. The subjects sat at a viewing distance of approximately 63 cm.

Each experimental trial consisted of four frames. Figure 2 illustrates what the four frames of a trial looked like (with some minor modifications to accommodate limitations of the printed page). The first frame was a white fixation cross (1°) presented for 250 msec on a dark gray background. The subjects were told to maintain fixation on this cross throughout each trial. The second frame added eight lighter gray circles (diameter = 3.7°) to the display, arrayed in a circle (radius = 6.8°) around the fixation cross. Empty circles alternated with circles containing two small (1°) figures. There were four types of such figures, representing the factorial crossing of color (red or blue) and shape (solid disk or empty box). The circles in Frame 2 that had two small figures in them were fillers; all of the relevant events (occurring in Frames 3 and 4) involved the initially empty gray circles. Frame 2 was presented for 750 msec.

In Frame 3, one new small figure (red or blue, disk or box) was added to one of the four empty circles. This was the cue event. The cue–target SOA was manipulated by varying the duration of Frame 3. SOAs of 600, 1,200, 1,800, 2,400, and 3,000 msec were tested.

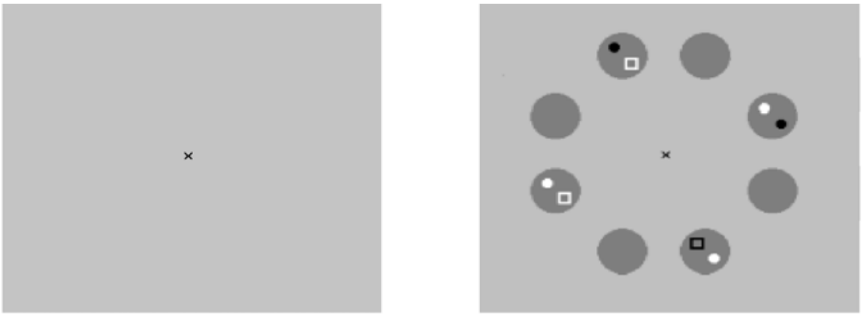
The target event was presented in Frame 4. One more small figure (red/blue, disk/box) was added to the display, and the subjects were told to hit a response button as soon as they detected the second new item. Both speed and accuracy were emphasized. The target could occur within the same gray circle as the cue (hereafter, *Same*), 90° away (*Diff1*), or 180° away (*Diff2*). IOR is indicated when Same targets are detected more slowly than Diff targets. For Diff1 trials, half of the targets occurred clockwise from the cue, and half occurred counterclockwise, randomly determined.

Figure 3 shows the target detection times found by Samuel and Weiner (2001), using these displays with SOAs between 80 and 610 msec. They found that for SOAs greater than 300 msec, target detection was fastest for the Diff2 case and slowest for the Same case, consistent with the view that IOR is strongest at the original cue location and dissipates with distance from there (e.g., Bennett & Pratt, 2001).

Each subject in Experiment 1 was presented with four passes of 76 trials. The 60 experimental trials within each pass included the factorial crossing of four possible cue locations × three possible target conditions × five SOAs. There were also 16 catch trials per pass, for which the cue appeared, but no target. The subjects were instructed to refrain from responding on such trials, since their responses were to be made upon the detection of the second figure's appearance. A new trial began 1,500 msec after the last response by a subject on the preceding trial or within 3,000 msec if a response was not made.

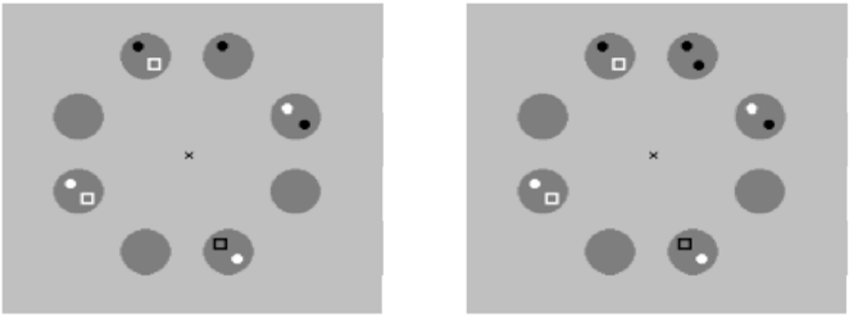
Results and Discussion

The data from 9 subjects were not included in the reaction time analyses, due to high error rates. For the ex-



(1) Fixation Display: 250 msec

(2) Initial Display: 750 msec



(3) Cue: Variable SOA

(4) Target: 3,000 msec Max

Figure 2. The four frames of a trial. To accommodate journal printing constraints, the small inner figures are shown in black and white, rather than in the blue and red that were used in the actual experiment. The background in the figure is lighter than the one in the actual displays, and the fixation cross is shown in black, rather than in white.

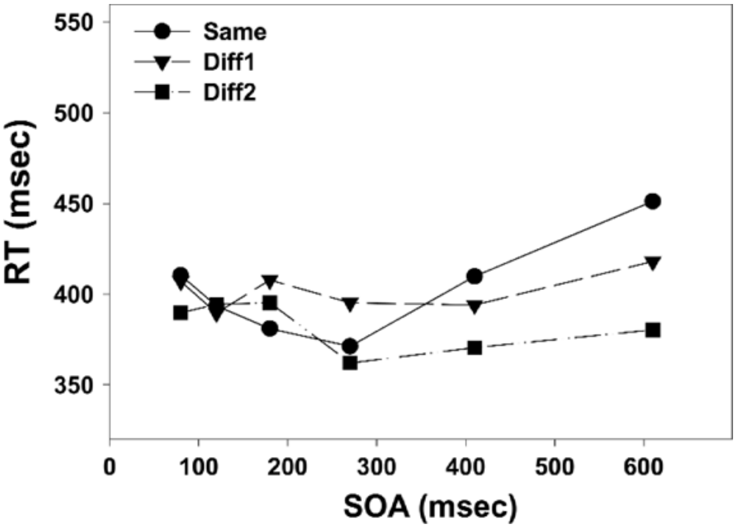


Figure 3. Target detection times, broken down by location (Same, Diff1, and Diff2) and stimulus onset asynchrony (SOA), from Samuel and Weiner (2001, Experiment 1).

cluded cases, the mean miss rate was 23.6%, and the mean false alarm rate was 5.7%. For the remaining 40 subjects, the miss rate was 3.0%, and the false alarm rate was 1.7%.

Figure 4 presents the mean target detection times, broken down by the location of the target (Same vs. Diff1 vs. Diff2) and the cue–target SOA. The primary goal of Experiment 1 was to determine whether IOR occurs at each of the tested SOAs, particularly at the later ones. An additional goal was to specify the spatial properties of IOR over time.

It is clear that IOR is present at each of the five tested SOAs, including the longest ones. There is also an intriguing change in the spatial distribution of IOR over time: At the 600-msec SOA, we replicated the pattern reported by Samuel and Weiner (see Figure 3), but for all of the other SOAs, the data for the Diff1 and Diff2 cases are virtually identical to each other.

These conclusions were supported by a set of simple comparisons. At each SOA, for each subject, we computed the difference in average detection time between the Diff1 and the Same case and between the Diff2 and the Same case. At each of the five SOAs, these difference scores were reliably greater than zero, confirming the presence of IOR [smallest $F(1,39) = 5.13, p < .03$]. For the 600-msec SOA, the difference between the Diff1 and the Diff2 differences from the Same case was also reliable, replicating the spatial distribution effect [$F(1,39) = 7.71, p < .01$]. In contrast, for all of the higher SOA conditions, reaction times to targets at Diff1 and at Diff2 did not reliably differ, with none of the differences reaching significance [largest $F(1,39) = 2.13$, n.s.].

The results of Experiment 1, therefore, permit two conclusions. First, the duration of IOR is at least 3 sec. Second, the spatial distribution of the inhibitory effect that has been found in several previous studies (e.g., Bennett & Pratt, 2001; Maylor & Hockey, 1985; Samuel & Weiner, 2001) appears to collapse after approximately 1 sec.

EXPERIMENT 2

The two main results of Experiment 1 were rather surprising, since neither was clearly expected on the basis of

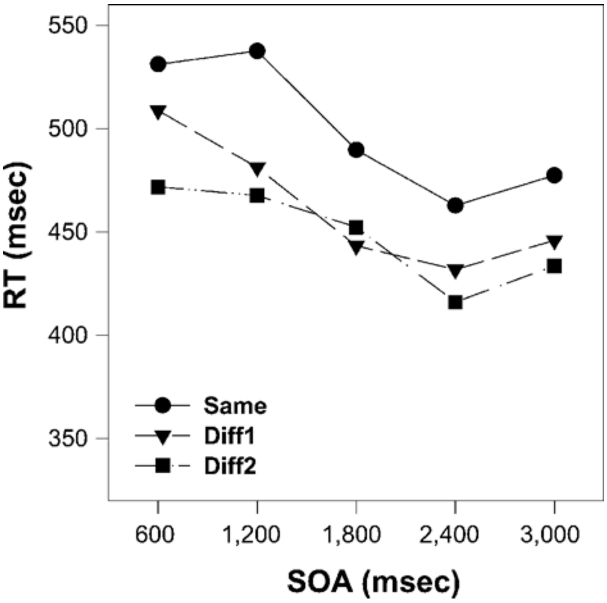


Figure 4. Target detection times in Experiment 1, broken down by location (Same, Diff1, and Diff2) and stimulus onset asynchrony (SOA).

previous findings in the literature. Our graphical meta-analysis had suggested that IOR might end by an SOA of 3 sec, yet Experiment 1 showed a reliable effect at this point. In addition, several previous studies, including one in which exactly the same display types were used, had shown a spatial gradient to IOR, yet this gradient completely disappeared beyond the 600-msec SOA. Experiment 2 was essentially a replication of Experiment 1, using a different (but overlapping) set of SOAs. The goal was to determine whether these two central results were replicable with a different mix of SOAs.

Method

Subjects. Forty-four SUNY, Stony Brook students received course credit for participating. All had normal or corrected-to-normal vision. From 1 to 3 subjects were tested at a time.

Apparatus and Procedure. The apparatus and procedure were identical to those in Experiment 1, except that a different set of SOAs was used. The new SOAs were 1,600, 2,000, 2,400, 2,800, and 3,200 msec.

Results and Discussion

The data from 4 subjects were not included in the reaction time analyses, due to high error rates. For the excluded cases, the mean miss rate was 14.0%, and the mean false alarm rate was 5.5%. For the remaining 40 subjects, the miss rate was 2.8%, and the false alarm rate was 1.4%.

Figure 5 presents the mean target detection times, broken down by the location of the target (Same vs. Diff1 vs. Diff2) and the cue–target SOA. The data were analyzed as in Experiment 1. As is clear in the figure, the new data replicated the essential findings of that experiment. For four of the five SOAs, the IOR effects for Diff1 and Diff2 did not differ significantly [$F < 1$ for SOAs of 1,600, 2,000, and 2,400 msec; $F(1,39) = 2.56$, n.s., for an SOA of 3,200 msec]. At the 2,800-msec SOA, the inhibitory effect at Diff2 was larger than that at Diff1 [$F(1,39) = 5.08, p < .05$]. IOR was substantial and significant at 1,600 msec (46 msec), 2,400 msec (37 msec), and 2,800 msec (54 msec) [smallest $F(1,39) = 8.99, p < .01$]. The 13-msec IOR effect at the 2,000-msec SOA did not reach significance [$F(1,39) = 1.53$, n.s.]. It appears that IOR may, in fact, be dissipating at the 3,200-msec SOA (as suggested by our graphical meta-analysis), with a 14-msec nonsignificant effect [$F(1,39) = 2.74$, n.s.]. However, the remaining trend prevents us from being able to say with certainty that IOR is, in fact, really ending at this point. Therefore, in Experiment 3, we extended the range of SOAs to 4,200 msec, to see whether IOR would definitely be gone by then.

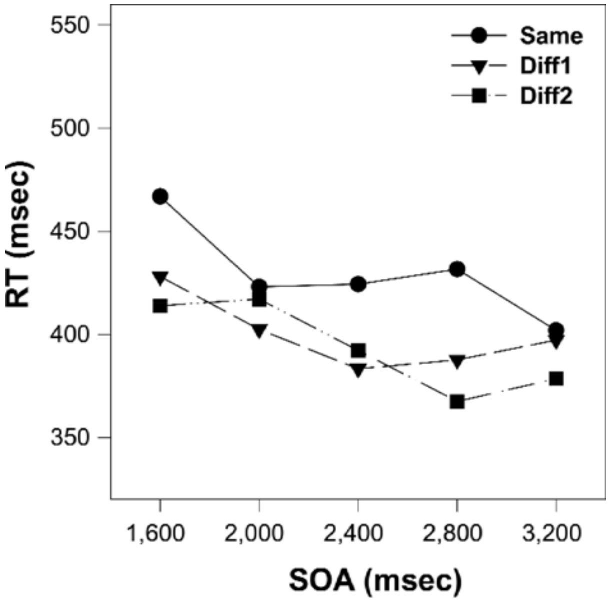


Figure 5. Target detection times in Experiment 2, broken down by location (Same, Diff1, and Diff2) and stimulus onset asynchrony (SOA).

EXPERIMENT 3

Experiment 3 included even longer SOAs than those used in the first two experiments. In addition, we used a more traditional set of displays. The type of displays used in the first two experiments (and by Samuel & Weiner, 2001) were more complex than those used in most IOR studies, with a greater number of filled locations on the screen and, arguably, with more subtle cuing events. These richer displays produced quite robust IOR effects. In fact, the effects in these experiments were about twice as large as those found with more typical displays. In Experiment 3, we used the more standard two-location type of display, to map the time course of IOR in a setting more like that used in most studies. We also used a triggering event (a brief brightening of one of those two locations) that is more typical. The central question remains the same: When does IOR finish?

Method

Participants. Forty-eight SUNY, Stony Brook students received course credit for participating. All had normal or corrected-to-normal vision. From 1 to 3 subjects were tested at a time.

Apparatus and Procedure. The apparatus and most procedures were similar to those in Experiments 1 and 2. However, different SOAs were used, in a simpler display, with a different initial triggering event. The new displays had only two circles, rather than eight, with the two circles located on either side of the fixation cross. Each circle was 6.2° from the cross, and each circle was 3.6° in diameter. The first frame of a trial was again the fixation cross, and the second one added the two (empty) circles. The third frame again contained the triggering event. However, in this case, the cue was a 50-msec brightening of one of the two circles. After a variable SOA, the target was presented in the center of one of the two circles. Targets were the same blue or red figures as before. The subjects were instructed to respond to the appearance of the targets.

The critical SOAs in Experiment 3 were 1,700, 2,200, 2,700, 3,200, 3,700, and 4,200 msec. Since these are quite long, we decided to include an equal number of trials with very short SOAs. These trials helped to keep the subjects focused on the task and on the fixation point, by preventing them from "drifting off" as they might have if there had always been long SOAs. These short SOAs were 70, 100, 130, 160, 190, and 220 msec. The design thus was 12 × 2 × 2: 12 SOAs, two cue locations (left vs. right circle), and two target locations (Same circle as the cue or Diff). These 48 unique trials were combined with 8 catch trials in which no target appeared. The resulting 56 trials were randomized and presented eight times. Collapsing across the right–left cue location yields 16 observations per SOA for both Same and Diff conditions. The task took approximately 36 min. The subjects were given a rest period halfway through.

Results and Discussion

The data from 10 subjects were not included in the reaction time analyses, due to very high variance in their reaction times (5 of these 10 were subjects run on the last day of the semester). The standard deviation for the reaction time in each cell of the design was calculated for all the subjects. For the excluded cases, 65% of these standard deviations were over 1,200 msec; for the subjects included in the analyses, only 5% exceeded this value. With the simple displays of Experiment 3, very few errors were made. For the excluded cases, the mean miss rate was 0.8%, as compared with a miss rate of 0.1% for the subjects included in the analyses. The corresponding false alarm rates were 1.7% for the excluded cases and 1.0% for those included.

Figure 6 presents the mean target detection times, broken down by the location of the target (Same vs. Diff) and the cue–target SOA. The data of primary interest (from the long SOAs) are plotted separately from the short SOA data, for the sake of clarity. As in Experiments 1 and 2, the primary analyses are simple comparisons at each SOA. Because the effects with the simpler displays are less than half the size of those in the more complex displays, we also analyzed the data using pairs of adjacent SOAs, increasing statistical power. This was particularly important in the present context, since we were looking for the disappearance of IOR and we needed to be sure that its statistical disappearance was not due to a lack of power.

Looking first at the short-SOA trials, we see that there is some evidence for a facilitation effect, at least for the 160-, 190-, and 220-msec SOAs. None of the individual simple comparisons reached significance, although two were marginal [160-msec SOA, $F(1,37) = 3.44, p < .08$; 220-msec SOA, $F(1,37) = 3.95, p < .06$]. The disadvantage at the 70-msec SOA for targets in the Same location as the triggering cue was also marginally significant [$F(1,37) = 3.40, p < .08$]. This pattern of results is consistent with the idea that the triggering cue, a flashing of the circle, produced a short forward-masking effect, hindering detection of targets in the Same location for about 100 msec. After that, the facilitation becomes apparent. In fact, by looking at pairs of SOAs, the facilitation reaches significance for the pair (190 and 220 msec) around 200 msec [$F(1,37) = 6.24, p < .02$]. Neither the middle two SOAs [$F(1,37) = 2.71$, n.s.] nor the two shortest [$F(1,37) < 1$] produced a reliable effect.

The results of interest in Experiment 3 are shown in the right panel of Figure 6. It is useful to consider these results in the context of the graphical meta-analysis shown in the top portion of Figure 1, since the testing conditions of Experiment 3 were designed to be consistent with those of the studies included in that figure. The shortest critical SOA tested in Experiment 3 (1,700 msec) produced a 19-msec IOR effect [$F(1,37) = 11.41, p < .005$]. Note that the 19-msec effect would fit perfectly into Figure 1. After this point, the data in Figure 1 become too sparse to be very informative (which is, of course, why we have run Experiments 1–3), with a single point at 2,400 msec and another at 3,200 msec.

The results of Experiment 3 indicate that under the most commonly used testing conditions, IOR disappears in under 3 sec, consistent with the sparse data in Figure 1.

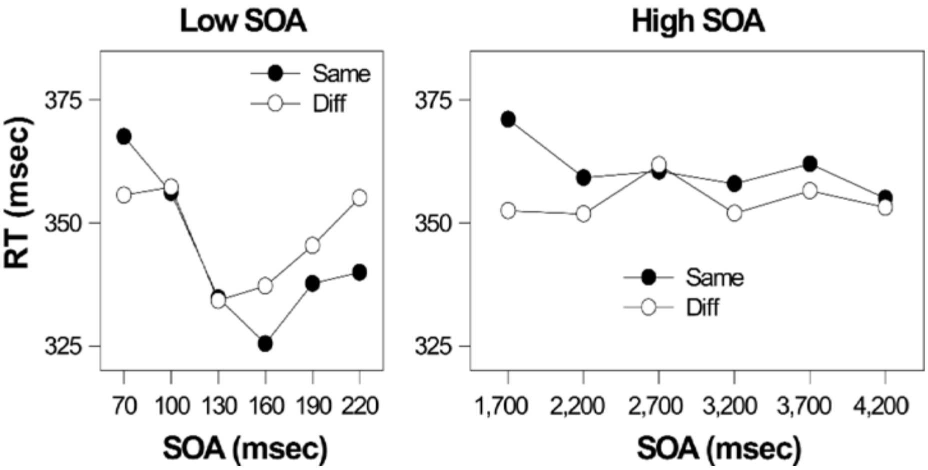


Figure 6. Target detection times in Experiment 3, broken down by location (Same and Diff) and stimulus onset asynchrony (SOA).

At 2,200 msec, the IOR effect is down to about 8 msec and is no longer significant [$F(1,37) = 1.12$, n.s.]. With the increased power obtained by combining the two SOAs around 2 sec (the 1,700- and 2,200-msec conditions), IOR is still quite reliable [$F(1,37) = 8.02$, $p < .008$]. In this case (and in all of the other cases in which we combined two SOAs), there was no effect of SOA (1,700 vs. 2,200 msec) nor any interaction of SOA with Same versus Diff, suggesting that it is reasonable to combine adjacent SOAs to increase statistical power. None of the higher SOA conditions produced a significant IOR effect [all Fs$(1,37) < 1$]. Moreover, even by combining pairs of adjacent SOA conditions, no IOR was present at either the 3-sec range [2,700 and 3,200 msec: $F(1,37) < 1$] or the 4-sec range [3,700 and 4,200 msec: $F(1,37) < 1$]. Thus, under the most standard testing conditions, IOR is present at around 2 sec, but is gone by 3 sec.

GENERAL DISCUSSION

Our graphical meta-analysis revealed the impressive stability of IOR for SOAs between 300 and 1,600 msec and illustrated the basis for the current controversy over effects at short SOAs. It also brought to light an important gap in our knowledge of IOR: The duration could not be pinned down by the existing literature. The results shown in Figures 4, 5, and 6 fill this gap. The measured duration of IOR, not surprisingly, varies a bit as a function of how it is measured. Under conditions that are most like those typically used, IOR ends sometime between 2 and 3 sec after the initial triggering event. If more complex displays are used, IOR is clearly robust out to 3 sec; it appears to dwindle shortly after that. Thus, with perhaps a bit of oversimplification, we may say that IOR lasts approximately 3 sec.

The present study also provides a useful summary of the spatial distribution of IOR as a function of time. Figure 7 presents this summary, using data from Experiments 1 and 2 of the present study and the corresponding experiment in Samuel and Weiner (2001). This figure plots the difference in detection times for targets in the Same location versus the Diff1 and the Diff2 locations. As the figure shows, IOR begins at SOAs beyond 300 msec and is robust out to 3 sec. The change in IOR's spatial distribution over this time period is clear. For SOAs between 300 and 600 msec, there is a spatial gradient to IOR, with points closer to the cue location producing worse performance than ones further away. At the longer SOAs tested in the present study, in contrast, performance was no better at the more remote Diff2 position than at the closer Diff1 position. In a set of experiments we recently completed (Samuel & Kat, 2003), we have replicated this initial spatial gradient, followed by its disappearance. Moreover, these recent experiments consistently showed this pattern across different locations (e.g., 80° and 160° as Diff1 and Diff2, rather than the 90° and 180° used here) and with various probabilities of targets in the Diff1 and Diff2 locations (e.g., 25% at each location, rather than the 16.5% at the Diff1 location and the 33.3% at the Diff2 location used here). Thus, the change from an initial spatially graded distribution of inhibition to one that is evenly spread is quite robust.

There are at least two classes of theories that could account for the shift over time from a spatially graded ef-

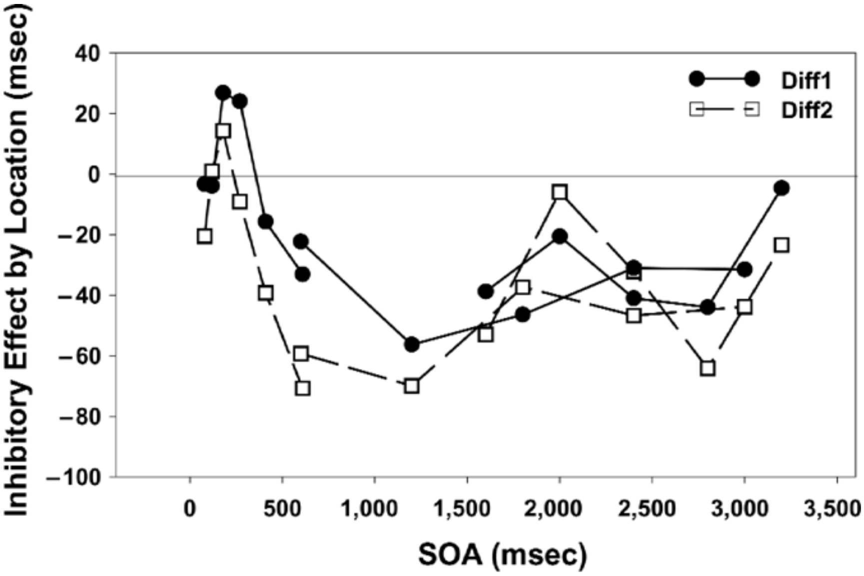


Figure 7. The difference in target detection times between Same and Diff1 and between Same and Diff2 as a function of stimulus onset asynchrony (SOA; short-SOA data from Samuel & Weiner, 2001; longer SOA data from Experiments 1 and 2).

fect to one that is spatially uniform. One possibility is that there are two components to the effect, with one component having a duration of only about 1 sec, and the other lasting about 3 sec. If the shorter-lasting process also had a narrower focus, the observed pattern would occur. Alternatively, in a single-process account, it is possible that the spatial extent of inhibition shrinks over time and that, after about 1 sec, this extent no longer encompasses targets at either Diff1 or Diff2, making them equivalent. The single-process account could be tested by using targets closer to the original cue location, as Pratt et al. (1999) and Snyder et al. (2001) have done.

The results of the present study may help to reconcile a current theoretical dispute between Pratt et al. (1999) and Snyder et al. (2001). Pratt et al. (1999) interpreted IOR in terms of what they called *attentional momentum*. This hypothesis is that after an initial visual event, attention moves away from the original cue's location and that changing the direction of attention's movement takes time. The spatially graded pattern of IOR is consistent with the attentional momentum hypothesis, and Snyder et al. questioned that hypothesis when they found no such spatial distribution under their testing conditions.

A critical issue in resolving the disagreement between these two sets of authors may well be the SOA in their tests. Pratt et al. (1999) used an SOA of 950 msec, and Snyder et al. (2001) used an SOA of 1,000 msec. Our data indicate that these values are precisely in the region of the temporal–spatial parameter space for which we would expect inconsistent results. That is, we now know that Pratt et al.'s (1999) pattern (a spatial gradient) is robust up to an SOA of 610 msec and that Snyder et al.'s pattern (no spatial gradient) is robust beyond an SOA of 1,200 msec. Snyder et al. found a small and inconsistent spatial distribution in their study, and their reanalysis of Pratt et al.'s (1999) data revealed a similar pattern. If both studies were, in fact, run within exactly the range of SOAs for which the spatial distribution is collapsing, this type of inconsistent-but-present effect is precisely what would be expected. Snyder et al. argued that the presence of a robust IOR effect in the absence of a spatial distribution implied that attentional momentum cannot be the basis of IOR and that the spatial distribution of performance was likely due to uninteresting, idiosyncratic, and inconsistent strategies. Our results suggest that the spatial distribution is, in fact, quite robust *at certain SOAs*, which is at odds with their dismissal of this factor. On the other hand, the strong IOR at the longer SOAs, in the absence of a spatial distribution, is consistent with their suggestion that there may be two components to the usually observed IOR effect, only one of which could be explained in terms of attentional momentum. There are a number of precedents in the IOR literature that could potentially map onto such a two-factor view (e.g., the object-based and the location-based components identified in earlier research).

Overall, the plot in Figure 7 is consistent with the results shown in our graphical meta-analysis (Figure 1). Moreover, although the size of the IOR effect in Experiment 3 was smaller than that in Experiments 1 and 2, the pattern of change over time was quite similar. This consistency suggests that this pattern is likely to be relatively constant for detection tasks with manual responses. Any functional account of IOR (e.g., as a "foraging facilitator"; Klein & MacInnes, 1999) must incorporate its spatial and temporal pattern. For example, for theories that associate IOR with mechanisms that plan eye movements, it will be important to demonstrate that those mechanisms show patterns of inhibition that follow the known temporal and spatial distribution of IOR. The empirical and meta-analytic approaches of the present study provide the best available information about this pattern and about the changes in the spatial pattern of inhibition over time.

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