Consequences of allocating attention to locations and to other attributes

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Simple reaction time to a light target may be lengthened when the light is preceded by a noninformative stimulus at the same location. This is known as inhibition of return. Does inhibition of return result if the relation between successive stimuli is defined in terms of color or orientation? Subjects pressed a key when a small square was displayed. In Experiments 1-3, location and color of the square were manipulated; there was inhibition of return based on location, but not on color. In Experiments 4-5, a confounding of color and luminance was eliminated, with no change in results. In Experiments 6-7, the background was composed of vertical stripes and the squares were composed of left- or right-oriented diagonal stripes. There was evidence of inhibition of return based on location, but not on orientation. These data support the idea that location is processed differently from other features.

It is well known that the speed of responding to a target is strongly influenced by the spatial relationship between the target and a previously displayed informative cue. For example, if the target falls in the same location as the cue (valid trials) 70% of the time and in each of three other locations (invalid trials) 10% of the time, mean reaction time (RT) is faster on valid trials than on invalid trials (e.g., Eriksen & Yeh, 1985; Posner, Snyder, & Davidson, 1980). Interestingly, even when the location of the cue is independent of the location of the subsequent target, and hence provides no information to the subject, RT is still influenced by the spatial relationship between the cue and the target. In particular, if the target occurs shortly after the cue (say, up to 150 msec), then RT is faster when the target is in the same location as the cue.

However, for longer cue-target intervals (say, from 300 msec to at least 1,500 msec), RT is slower when the target appears in the same location as the cue (e.g., Maylor & Hockey, 1985; Posner & Cohen, 1984; Posner, Cohen, Chohate, Hockey, & Maylor, 1984; Possamai, 1986; Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987).

In Posner and Cohen's (1984) experiment, subjects were presented with three boxes—one to the left, one at the center, and one to the right of a screen. A trial began with the brightening of one of the peripheral boxes for 150 msec, which served as a visual cue. A small dot that served as a target appeared in the center of one of the boxes 0-500 msec following the onset of the cue. The target appeared in the center box with probability .6 and in one of the peripheral boxes with probability .1. Catch trials occurred with a probability of .2. Subjects were required to press a key upon detection of the target. When the cue preceded the target by up to 100 msec, mean RT for the detection of the target was less when the target appeared at the cued position than when it appeared at the opposite position. This initial facilitation of the cued side was attributed to the summoning of attention by the cue (see also Yantis & Jonides, 1984).

However, for cue-target intervals from 300 to 500 msec, a target on the cued side was responded to more slowly than was one on the opposite side. Therefore, the early facilitation to the cued side was replaced by a subsequent inhibition. This was called inhibition of return. It was assumed that after being drawn to a peripheral location by the cue, attention returned to the center location. This was plausible since the probability of target presentation was much higher at the center than for either of the peripheral locations. Subsequent experiments suggested that inhibition lasted up to 1.5 sec.

Several alternative explanations of the observed inhibition and facilitation effects have been tested. First, Posner and Cohen (1984) found that the inhibition and facilitation effects were still obtained using four peripheral boxes. This ruled out explanations based on the fact that only two peripheral positions were used as possible target positions in the original experiment. (For example, if subjects failed to find the target at the cued location shortly after the cue appeared, they may have guessed that it was more likely to occur at the other position.)

Second, Posner and Cohen (1984) found that the two effects were unchanged when subjects were cued by the dimming of the peripheral box rather than by the bright-
ening of it. This result ruled out the explanation that the facilitative effect is due to enhancement of subsequent sensory processing by a luminance increase.

Third, Maylor and Hockey (1985) found an inhibitory effect in a paradigm that required subjects to respond to each of a series of targets, where target N+1 was presented a fixed time after the occurrence of the response to target N. (That is, the “cue” in this experiment was the preceding target, and the response–stimulus interval (RSI) was manipulated from trial to trial.) Responding to a target presented at the same location as the previous target was slower than to a target at the opposite location. Thus, inhibition of return is not dependent on the use of a paradigm in which a motor response to the cue needs to be inhibited.

Fourth, when a central, symbolic (arrow) cue was used instead of a peripheral cue to orient attention, Posner and Cohen (1984) found that the facilitative effect was still obtained, whereas the inhibitory effect disappeared, suggesting that orienting of attention itself is not sufficient for obtaining inhibition of return. In other words, it is necessary to use a visual cue that can involuntarily and automatically summum attention (e.g., peripheral cue onset) in order to get an inhibitory effect.

Finally, when both peripheral boxes were cued, the facilitation effect was diminished, whereas the inhibition effect was, if anything, slightly increased. Assuming attention cannot be split between noncontiguous locations (Posner, Snyder, & Davidson, 1980), this double-cue effect suggests that the inhibition does not arise from attentional orienting but from the energy change present at the cued position (Posner & Cohen, 1984). However, Maylor (1985, Experiment 3), using a double-cue technique similar to that of Posner and Cohen (1984), found that both inhibition and facilitation were reduced by double cuing. This implies that orienting is necessary for inhibition to occur. It is not yet clear why these two very similar studies yielded different results. Further experiments are needed to resolve this apparent conflict.

In summary, a peripheral visual stimulus both summons attention and subsequently inhibits the processing of further information at that spatial location. The relation between the facilitative and inhibitory effects is not yet firmly established, but they may well be independent, since one effect has been found in the absence of the other (Posner & Cohen, 1984). The results of the symbolic-cue experiment suggest that inhibition may depend primarily upon sensory information rather than attentional orienting. However, it is far from clear what aspect of sensory information is responsible for the inhibition, since it is also far from clear just how the relevant aspect of sensory information ultimately causes inhibition (for some possible mechanisms, see Possmayer, 1981; Tassinari et al., 1987).

Several theorists have considered the possible functional significance of inhibition of return. Posner and Cohen (1984) suggested that the inhibition of return tends to maximize sampling of the visual environment. In other words, the inhibition effect reduces the tendency to sample locations that have just been sampled. This idea has been tested in the context of a visual search task. Klein (1988) had subjects search for a conjunctively defined target, which presumably requires a serial search of the display (Treisman & Gelade, 1980). On half of the trials, 60 msec after responding to the conjunctive target (and, thus, about 700–1,800 msec after the presentation of that target), a small bright spot was presented either at the position of the stimulus in the previous display or at a position that was not occupied. He reasoned that if inhibition of return operates in visual search to increase sampling efficiency, then subjects would take more time to detect the probe dot presented at one of the positions previously attended than to detect the dot when it appeared at a position that was unoccupied on the previous trial. The results confirmed the prediction. In addition, the feature search condition, which presumably did not require attentional processing, did not yield a subsequent inhibition of return in the probe display. However, a more recent study with similar procedures failed to replicate that result (Wolfe & Pokorny, 1990). Since it is difficult to determine what may have caused the discrepancy, it is not yet clear whether inhibition of return plays a role in serial search tasks.

Searching for Inhibition of Return in Other Domains

While all the above studies deal with location-based inhibition of return (which we shall shorten to location-based inhibition), we were interested in determining whether similar inhibition effects can be obtained in other stimulus domains, such as color, orientation, or form. If inhibition of return is found only in the domain of spatial location, it may be that spatial location is special, relative to other stimulus domains (e.g., Nissen, 1985). In contrast, if we find inhibition of return for other domains as well as location, this would be an argument against the uniqueness of spatial location.

Several investigators have argued that the various dimensions of a stimulus are basically the same, so that location is not special. Duncan (1980) argued that “the difference from selection based on spatial position or color seems quantitative rather than qualitative” (p. 293). In other words, if the discriminability of color and position are held equal, then there would be no difference in the efficiency of selection. Egeth, Virzi, and Garbart (1984) demonstrated that subjects could search effectively through a subset of items defined by a color in conjunctive displays, resulting in flat search functions. Their results parallel those of Treisman and Gelade (1980), who demonstrated that presenting a spatially precise prior to presenting a conjunctive display eliminated the need to search the display serially. Together, such studies suggest that a search based on location is not qualitatively different from a search based on color.

Bundesen (1990) proposed a theory of visual attention in which visual recognition and attentional selection consist in making perceptual categorizations. Examples of the perceptual categories are the class of red elements, the
class of letters of type A, and the class of elements located at fixation. Bundesen did not distinguish the color category from the location category, assuming the same mechanisms for attentional selection of these categories. If the difference in the manner of attentional selection between location and color is only quantitative rather than qualitative, then location is not special, and we should obtain inhibition effects in other domains.

In contrast to those arguing location is not special, Nissen (1985) argued for the uniqueness of location in the selection of visual information. She argued that in a "single-map" task in which subjects are either cued with a location and asked to report the color of the stimulus at that location or cued by a color and asked to report the location of the stimulus bearing that color, there should be no special advantage for selection by location. She went on to argue that in a task requiring "cross-referencing" between maps (e.g., cueing with a location and asking for the color and shape at that location or cueing by a color and asking the location and shape of the colored item), the results should be different. Specifically, in the location-cue condition, the probabilities of reporting color and shape should be independent. In contrast, in the color-cue condition, the probability of reporting shape should be dependent on the probability of reporting location. The results were in conformity with her arguments, suggesting that subjects used a location map to link color and shape maps. Therefore, it was suggested that location is special in the selection of attributes (however, see Bundesen, 1991, for an alternative explanation).

While there are no reports of inhibition of return to attributes other than location, there are somewhat similar interference effects due to the repetition of attributes presented in a temporal (Kanwisher, 1987) or spatial manner (Bjork & Murray, 1977; Egeth & Santee, 1981; Estes, 1982; Kim & Kwak, 1990; Santee & Egeth, 1980). When letters or words are presented in a rapid serial visual presentation (RSVP), subjects often have difficulty in identifying a repeated letter (called repetition blindness; see Kanwisher, 1987; Kanwisher & Potter, 1990). Kanwisher (1987) argued that repetition blindness occurs when words or letters are recognized as types but are not individuated as tokens. It should be noted, however, that the time course of repetition blindness is much shorter (usually less than 200 msec of SOA) than that of inhibition of return. The negative repetition effect, or repeated-letter-inferiority effect, first found by Bjork and Murray (1977), arises when subjects are required to identify a target letter cued by an arrow in a briefly presented display. Detection accuracy for the cued target letter was lower when the target was accompanied by a noise-same-as-target letter than when the target was presented alone or was accompanied by a noise-alternative-target letter. Although the relations of the repetition effects to inhibition of return are not yet entirely clear, they at least serve as additional demonstrations that stimulus repetition may impair performance.

EXPERIMENTS 1–3

The first three experiments used a continuous-responding paradigm, in which subjects were instructed to respond to every display in a series. We examined whether inhibition effects would be obtained in the color domain. In other words, would responses to a stimulus of the same color as the preceding stimulus be slower than responses to a stimulus of a different color from the preceding stimulus? If the inhibition operates only in the spatial domain, then there is no reason to expect color-based inhibition of return (which we shall shorten to color-based inhibition). However, if inhibition of return is related to sensory processing in general and is not confined to location processing, then it may be possible to obtain color-based inhibition.

In Experiment 1, we examined both color- and location-based inhibition, using the continuous-responding paradigm of Maylor and Hockley (1985). Four colors and four positions were used. In Experiment 2, we used two colors and two positions in order to examine the interaction between color and location more precisely. In Experiment 3, each square color box was presented at the center position of the screen. This allowed us to examine the possibility of color-based inhibition while eliminating the complication due to the variability in spatial location.

Method

Subjects. The same 9 subjects participated in Experiments 1, 2, and 3, consecutively in a single session as part of a course requirement. Each experiment took about 10 min. All subjects had normal or corrected-to-normal vision.

Stimuli and Apparatus. An IBM PC/AT with ATI VGA Wonder Card and a NEC Multisync VGA Monitor were used to present stimuli and to measure RTs. In Experiments 1, 2, and 3, each target was a 0.25" x 0.25" colored square on a black background. In Experiments 1 and 2, the target appeared 3.8° from the central fixation point; in Experiment 3, the targets were presented at the fixation point. Viewing distance was approximately 50 cm.

Designs. In Experiment 1, four colors (red, yellow, green, and blue), four positions (above, below, right of, and left of the fixation point), and four levels of RSI (300, 400, 500, and 900 msec) were combined factorially. Thus, a given stimulus (e.g., blue presented in the position above fixation after an RSI of 400 msec) could be any of 64 possible stimuli. Each of these 64 possible stimuli was presented once in a block of trials.

What is critical in the design and analysis of this experiment is the relation of a given stimulus to the one that came before it. Specifically, 25% of the trials were same-color trials, in which the colors of the present stimulus and the preceding stimulus were the same, and 75% were different-color trials. Similarly, 25% were same-position trials, 50% were adjacent-position trials, and 25% were opposite-position trials. (Because these factors were independent, 6.25% of the trials were both same color and same position, etc.) Furthermore, for each combination of color status (same or different) and location status (same or different), equal numbers of trials were presented at each of the four levels of RSI. For the purpose of design and analysis, then, Experiment 1 was a 2 (same vs. different color) x 3 (same, adjacent, and opposite positions) x 4 (RSIs) repeated measures design. Note, as described above, that the levels...
of these factors were not equally probable. There were five blocks of 64 trials each. (Actually, each block consisted of 65 trials. However, the response to the first trial was excluded from analysis, since it was not preceded by another trial.)

In Experiment 2, combinations of two colors (red and green), two positions (left and right), and four levels of RSI (300, 500, 900, and 1,400 msec) were manipulated, resulting in a 2 (same vs. different color) × 2 (same vs. different position) × 4 (RSIs) design. Unlike Experiment 1, same- and different-color trials and same- and different-position trials were equally frequent in each block. To prevent any anticipatory response resulting from short RSI ranges, a longer (1,400-msec) RSI was included in Experiments 2 and 3. There were 10 blocks of 32 trials (16 trial types × 2 repetitions).

In Experiment 3, all stimuli appeared at fixation. Four colors (as in Experiment 1) and four levels of RSI (as in Experiment 2) were factorially combined, resulting in a 2 (same vs. different color) × 4 (RSIs) repeated measures design. In each block, 25% of the trials were same color and 75% were different color. There were 10 blocks of 32 trials in Experiment 3. The order of presentation of trials within a block was randomized.

Procedure. The subjects were tested individually in a dimly lit room. They were instructed to respond as quickly as possible to the onset of a colored square by pressing a button on a keyboard with the dominant hand. Each block of trials began with the presentation of a central + sign, which served as an initial fixation point. The fixation point was displayed for a duration randomly selected in the range of 1.5–2.5 sec, followed immediately by the first display. The first display consisted of a color square presented in one of the permissible locations (four positions in Experiment 1, two positions in Experiment 2, and one position in Experiment 3) and remained on until the subject responded. Response to the first display was not included in the analysis. At a designated RSI after response, the next colored target square was presented. The procedure is illustrated in Figure 1 for the two-location two-color condition used in Experiment 2.

Once a block was begun, stimuli were presented successively at the appropriate RSI without pause until the block was completed. The subjects were encouraged to respond as quickly as possible while not making any premature responses or moving their eyes during a trial. At the end of each block, the subjects were allowed to rest several minutes before starting another block, which was initiated when the subject pressed a key.

Results and Discussion

RTs faster than 150 msec or slower than 1,000 msec were excluded from analysis. The proportion of these premature or slow RTs was low (1.6% in Experiment 1, 1.6% in Experiment 2, and 2.4% in Experiment 3).

Mean RTs for each condition in Experiment 1 are presented in Figure 2. A three-way repeated measures analysis of variance (ANOVA) was performed on the mean RTs. There were significant main effects of location (same vs. different) $[F(1,8) = 37.61, p < .001]$ and RSI $[F(3,24) = 26.74, p < .001]$, but the effect of color (same vs. different) was not significant $[F(1,8) = 1.4, p > .05]$. The general decrease in mean RT as RSI increased is similar to many previous findings in the literature (e.g., Bertelson, 1967; Requin & Granjon, 1969).

When target $N$ was in the same location as target $N-1$, RTs were consistently slower than when target $N$ was either in the adjacent or in the opposite location from target $N-1$, indicating location-based inhibition at all levels of RSI. Mean RTs were 349 msec in the same position, 311 msec in the adjacent position, and 308 msec in the opposite position. There was no difference between adjacent position and opposite position $[F(1,8) = 1.44, n.s.]$, whereas there was significant difference between same position and adjacent position $[F(1,8) = 41.51, p < .001]$, as shown in Figure 2. This replicates previous findings of inhibition effects involving location (Maylor & Hockley, 1985). In addition, the magnitude of location-based inhibition is comparable to that reported by Maylor and Hockley (1985). However, there was no indication of color-based inhibition in Experiment 1, as shown in Figure 2. Mean RTs were 325 msec on same-color trials and 321 msec on the different-color trials.

Figure 3 shows mean RTs for each combination of position, color, and RSI in Experiment 2. As shown, a significant location-based inhibition was obtained (332 vs. 292 msec) $[F(1,8) = 45.59, p < .001]$. The main effect of RSI was also significant $[F(3,24) = 30.37, p < .001]$, but there was no indication of color-based inhibition (313 vs. 312 msec) $[F(1,8) < 1]$. Color and position interacted significantly $[F(1,8) = 7.15, p < .05]$. Specifically, a small amount of color-based inhibition was obtained in the same position (335 vs. 330 msec) $[F(1,8) = 7.28, p < .05]$, whereas there was a slight but nonsignificant tendency toward facilitation in the different position $[F(1,8) = 1.83]$. Though significant in the same-position condition, color-based inhibition was quite small (5 msec). In view of the overall pattern of results reported in this paper, we doubt that this is a replicable result.

In Experiment 3, the stimuli always appeared at the center. Figure 4 shows mean RTs for the same-color and different-color conditions at each level of RSI in Experiment 3. A 2 (same vs. different color) × 4 (RSIs) repeated measures ANOVA was performed. The main effect of RSI was significant $[F(3,24) = 36.81, p < .001]$, but
Figure 2. Mean reaction time as a function of response–stimulus interval (RSI), color, and position in Experiment 1.

Figure 3. Mean reaction time as a function of response–stimulus interval (RSI), color, and position in Experiment 2.

Figure 4. Mean reaction time as a function of response–stimulus interval (RSI) and color in Experiment 3.

there was no indication of color-based inhibition (299 vs. 298 msec) \(F(1, 8) < 1\). The interaction between RSI and color was not significant \(F(3, 24) < 1\).

Since there is no true neutral condition in any of the present experiments, it is not easy to determine whether the effect we have observed is due to inhibition at the cued position or facilitation at the uncued position(s). However, we have at least one reason to believe that the effect is inhibitory. Specifically, there were three uncued positions in Experiment 1, but just one uncued position in Experiment 2. On most readily imaginable accounts of facilitation, there should thus be less facilitation in Experiment 1. However, the magnitude of the location-based effect was essentially the same in the two experiments. For this reason, we prefer the inhibition hypothesis.

The results of Experiments 1, 2, and 3 suggest that responding to a color does not produce an inhibition of return to color analogous to the inhibition of return that occurs in the domain of spatial location. In other words, the chief result is that it does not take more time to respond when the current stimulus is the same color as the preceding stimulus than when the current stimulus is a different color from the preceding stimulus.\(^4\)

**EXPERIMENTS 4 AND 5**

It might be argued that the lack of color-based inhibition in the first three experiments may have been attributable to the abrupt luminance changes accompanying the presentation of the colored targets.\(^5\) In Experiments 1–3, bright colored squares were successively presented on a black background. It is conceivable that the subjects responded on the basis of the luminance change; color may have been irrelevant. Therefore, the lack of color-based inhibition in Experiments 1, 2, and 3 does not necessarily mean that color-based inhibition does not exist. Of course, the same could be said of position (i.e., it is irrelevant because the subjects did not have to process positional information to perform the task). But it may be the case that abrupt onset draws attention more quickly to location than to color. This difference in initial time course may be the basis for the difference in results pertaining to inhibition of return.

One way to eliminate the confounding of luminance and color is to present color stimuli on a gray background that is equiluminant with the colored stimuli. Although our equipment did not allow an exact match of luminance, the approximation we achieved seemed quite good. In any case, in Experiments 4 and 5, the apparent change in luminance when stimuli were presented was drastically reduced, relative to that of Experiments 1–3.

In Experiment 4, the task and stimuli were the same as those in Experiment 2, except that near-equiluminant color stimuli were used in Experiment 4. One of our purposes in Experiment 4 was to examine whether the small
color-based inhibition obtained in Experiment 2 would still be obtained using equiluminant color stimuli. In Experiment 5, we examined whether color-based inhibition would be obtained in the cuing paradigm used by Posner and Cohen (1984).

Method

Subjects. Ten subjects participated in Experiments 4 and 5 in a single session to fulfill a course requirement. All had normal or corrected-to-normal vision.

Stimuli and Apparatus. Using the minimal flicker method (Troschianko & Low, 1986), the luminance level of each color and background was initially set to yield the nearest equiluminant colors to the background gray for each subject; these levels remained fixed throughout Experiments 4 and 5. Other aspects of the stimuli in Experiments 4 and 5 were the same as those in Experiment 2.

Design. The design of Experiment 4 was the same as that of Experiment 2 (the differences were in the stimuli, not the design). In Experiment 5, color (same and different), position (same and different), and stimulus-onset asynchrony (SOA; 500, 700, 900, and 1,400 msec) were combined factorially. Each of the five blocks of trials in the experiment contained 64 trials, four repetitions of each of the 16 trial types.

Procedure. The procedure of Experiment 4 was the same as that of Experiment 2 (continuous-responding paradigm). In Experiment 5, the subjects were presented with a pair of successive displays, each containing a single small colored square either left or right of the fixation point. The first display was presented for 300 msec and was followed—a variable SOA, ranging from 700 to 1,300 msec—by the second display. On half of the trials, the positions of the squares in the first and second displays were the same; on the other half of the trials, the positions were different. Independently, on half of the trials, the colors of the squares in the two displays were the same, and, on the other half, they were different. The subjects were required to press a key upon the presentation of the second colored square in each pair, which remained on until they responded; however, they were told not to respond to the first colored square, which was presented briefly (300 msec).

Results and Discussion

Mean RTs for each condition in Experiment 4 are presented in Figure 5. A three-way repeated measures ANOVA on mean RTs in Experiment 4 was performed. There was significant location-based inhibition (326 vs. 294 msec) [F(1,9) = 38.74, p < .001]. The main effect of RSI [F(3,27) = 7.51, p < .01] and the interaction between color and RSI [F(3,27) = 6.66, p < .01] were also significant. This interaction was due to the presence of a color-based facilitation at an RSI of 300 msec [F(1,9) = 25.55, p < .001] and the absence of color-based facilitation and inhibition for longer RSIs. The interaction between RSI and position [F(3,27) = 4.82, p < .01] indicates that the amount of location-based inhibition decreases as RSI increases. Interestingly, the small color-based inhibition obtained in one condition of Experiment 2 disappeared in Experiment 4, which used equiluminant color stimuli. Of course, the use of equiluminant stimuli was intended to force the processing of color, thereby increasing the probability of finding color-based inhibition if such a phenomenon in fact exists. The absence of color-based inhibition in Experiment 4 implies that the small color-based inhibition effect of Experiment 2 may not be reliable.

Figure 6 shows mean RTs for each condition in Experiment 5. A 2 (same vs. different color) × 2 (same vs. different position) × 4 (SOAs) ANOVA on the mean RTs was conducted. As in Experiment 2, there was no indication of color-based inhibition (344 vs. 342 msec) [F(1,9) < 1], but there was a significant location-based inhibition (360 vs. 327 msec) [F(1,9) = 20.256, p < .01], as well as a significant main effect of SOA [F(3,27) = 19.06, p < .001]. The results of Experiment 5 suggest that changing the task from a continuous-responding paradigm to a cue-target paradigm and making the displays approximately equiluminant did not change the primary results; location-based inhibition was still present and color-based inhibition was still absent.

Experiments 6 and 7

Experiments 1–5 tested for the existence of color-based inhibition. Because one purpose of this research was to examine whether location is special relative to other stim-
INHIBITION OF RETURN

Figure 7. Sample stimulus display example used in Experiments 6 and 7.

In other domains, it is of interest to include a stimulus domain other than color to expand the generality of our results. One possible candidate is orientation. In Experiments 6 and 7, we examined whether an inhibition effect would be obtained based on orientation (orientation-based inhibition) by presenting one of two diagonally striped gratings on a uniform background of vertical lines. Moreover, since the background grating and target grating had the same average luminance level, these two experiments served as another attempt to test whether luminance change is crucial to obtaining inhibition of return.

Method

Subjects. Ten subjects participated in Experiment 6; 8 different subjects participated in Experiment 7. The subjects who served in Experiment 6 had also served in Experiments 4 and 5, in a single experimental session.

Stimuli and Apparatus. The background was a grating of vertical lines of 1 mm thickness, with 0.38°/cycle. The target and/or cue stimulus was a 1.15° × 1.15° square containing either a left- or right-sloped grating (see Figure 7). The bandwidths of the slanted grating and the background grating were the same, so that the subject could not respond on the basis of overall luminance.

Design and Procedure. The design and procedure (continuous-response paradigm) of Experiment 6 were essentially the same as those of Experiments 2 and 4, with orientation (left and right diagonal) taking the place of the colors (red and green) used in the earlier experiments.

The design and procedure (cuing paradigm) of Experiment 7 were essentially the same as those of Experiment 5, again with the proviso that orientation took the place of color.

Results and Discussion

Figure 8 shows mean RTs for each condition in Experiment 6. A three-way ANOVA on mean RTs in Experiment 6 was performed. There were significant effects of location-based inhibition (339 vs. 308 msec) \([F(1,7) = 47.79, p < .001]\) and RSI \([F(3,21) = 6.71, p < .01]\). In addition, the interaction between position and RSI was significant \([F(6,48) = 4.00, p < .01]\). More interestingly, the main effect of orientation was significant \([F(1,9) = 12.54, p < .01]\), indicating that responding to a grating of the same orientation as the preceding target was faster than responding to a grating of a different orientation (319 vs. 328 msec). The amount of this facilitation was the same, regardless of whether targets were in the same or different locations. However, before attaching too great a significance to this effect, it is worth noting that the effect was quite small (9 msec).

The results of Experiment 7 are, on the whole, consistent with those of Experiment 6. Mean RTs for each condition are shown in Figure 9.

A three-way ANOVA on mean RTs in Experiment 7 was performed. There were significant effects of location-based inhibition (337 vs. 302 msec) \([F(1,7) = 62.97, p < .001]\) and RSI \([F(3,21) = 27.29, p < .001]\). In addition, the interaction between position and RSI was significant \([F(3,21) = 13.28, p < .001]\). Unlike Experiment 6, the main effect of orientation was not significant (318 msec for same orientation, and 321 msec for different orientation).
ent orientation) \(F(1, 7) = 2.52, p > .1\), indicating that there was neither inhibition nor facilitation based on orientation.

To summarize to this point, there is no evidence of an inhibition effect based on either color or orientation. However, because the equiluminance control of Experiments 4 and 5 was not perfect, it would certainly be helpful to do further research using other manipulations to separate possible color-based effects from luminance effects. For now, we have no evidence for inhibition of return based on any attribute other than location.

**GENERAL DISCUSSION**

The major purpose of the present study was to examine the consequences of orienting to a specific location and orienting to specific levels of other attributes. Specifically, we examined whether there would be inhibition of return in stimulus domains other than location (e.g., color and orientation). This issue is important because it speaks to the issue of whether spatial location is special and different from other attributes.

In Experiments 1–3, we examined whether color-based inhibition would be obtained, while trying to replicate location-based inhibition obtained in previous studies. There was no indication of color-based inhibition in any of the three experiments, except for a small (5-msec) color-based inhibition in the same-position condition in Experiment 2. The overall lack of evidence for color-based inhibition might have been due to the possibility that either (1) the subjects did not process the color of the target square, because the presentation of a colored square was confounded by a luminance increase, or (2) orienting to locations and orienting to color may be fundamentally different.

To examine further the lack of color-based inhibition in the first three experiments, the second set of experiments employed approximately equiluminant displays. Using a continuous-responding paradigm in Experiment 4 and a cue-target paradigm in Experiment 5, we found anything indication of color-based inhibition, although we found the typical pattern of location-based inhibition. The results of Experiment 6 (with orientation gratings as target and background stimuli) revealed no orientation-based inhibition; to the contrary, they revealed a small facilitative effect of orientation, along with the usual inhibition of return based on location.

From the results of the seven experiments, it is clear that there is no inhibition of return for color or orientation. Therefore, the results of these experiments suggest that location is not functionally the same as at least some other stimulus attributes, in agreement with Nissen’s (1985) argument. Clearly, an attribute such as color can be conceived of as having a spatial character. For example, the color solid shown in many introductory textbooks is a way of representing relations among colors in three spatial dimensions. However, it would appear that one should not take that metaphorical use of space too literally in attempting to make predictions about the orienting of attention.

It is not yet clear what aspect of sensory stimulation is responsible for inhibition of return. However, the present experiments at least help to clarify what is *not* important. We now know that a marked luminance change is not necessary to obtain the standard inhibition of return based on location. This was by no means obvious in advance, since several well-known perceptual phenomena either disappear or are markedly reduced in magnitude when equiluminant displays are used. To cite just one example, Cavanagh (1987) has shown that subjective contours can only be seen if the figures are defined by luminance changes.

Our data also show that it may be possible to demonstrate facilitation with equiluminant stimuli. However, the case is not as clear as it is for inhibition. The positive evidence comes from Experiment 6, in which a general facilitation of responding was found for stimuli of the same orientation as that of the preceding stimulus, and from Experiment 4, in which a color-based facilitation was found in a rather specific combination of conditions. Specifically, responses to a repetition of a color were faster than responses to a change in color on successive trials, but only at the shortest RSI and when the squares were in different positions on the successive trials. We have no explanation at this time for the spatial specificity of this effect. It may well simply represent a statistical fluke. It is important to keep in mind that our experiments were not designed to explore facilitation—not this effect is typically found only in the cue paradigm at short SOAs. Indeed, perhaps the most important point that needs to be made about the facilitation effect is that it is sometimes weak or nonexistent even in the cue paradigm (e.g., Experiments 3 and 7 of the present paper; Posner et al., 1984, Experiments 3 and 4; Posamai, 1986, 1991). It may not be a real effect at all.

**REFERENCES**


**NOTES**

1. We ran several experiments, trying to replicate the results of the double-cue experiment by Maylor (1985), with slight modifications in the stimulus display. We reasoned that the baseline for calculating the inhibitory effects of single- and double-cue conditions may be different, because a double cue may have a greater alerting effect than does a single cue. This would lead to the double-cue condition's being generally faster than the single-valid cue condition, resulting in a smaller inhibition effect. To avoid this problem, we used four locations instead of two, and we compared valid and invalid single cues and valid and invalid double cues. We also compared double cues that were presented simultaneously versus ones presented sequentially. In our experiments, we could find no difference in the amount of location-based inhibition between single- and double-cue trials, suggesting that attentional orienting may not be the source of inhibition of return. Data from double-cue conditions will be reported more fully elsewhere.

2. Location can be defined as retinal or environmental (Posner & Cohen, 1984). For example, when an object moves and subjects' eyes are tracking its movement, then the object is in the same location on the retina, but it is in different environmental locations as it moves. Inhibition of return has been shown to remain at the attended environment location, even when eye movements cause the eye movements to change (Posner & Cohen, 1984). However, recent evidence suggests that the relevant reference frame may be object centered (Tipper, Driver, & Weintraub, 1991).

3. It was only when we received the reviews of the first draft of this paper (in early 1983, Maylor, Posner, & Cohen, 1984, pp. 217-222) that we had conducted an experiment manipulating color in addition to location. She found a small and marginally significant amount of color-based inhibition ($p < .06$). However, there are several differences between Maylor's experiment and ours. In her experiment, location and color were not completely orthogonal. Two pairs of LEDs were used. Each pair contained one green and one red LED, and was centered $2^\circ$ left or right from fixation. Most importantly, LEDs cannot be superimposed; the two LEDs in each pair were separated by $0.6^\circ$. Consequently, as Maylor pointed out, the small effect due to color might actually be due to location, but this cannot be asserted with any confidence. In addition, we examined the effect of color and location in a greater variety of situations (i.e., one, two, and four locations; two and four colors), and we also examined the effect of an orientation manipulation.

4. It is possible that location-based inhibition found in Experiments 1 and 2 may be due to eye movements. (We thank Tram Neill and C. W. Eriksen for pointing out this potential problem.) Between the presentation of stimulus S and stimulus S+1, there was sufficient time for at least two eye movements. It is possible that subjects may have moved their eyes first to the cued location and then to the uncued location. Thus, at the time stimulus S+1 was presented, the subject may have been fixated on an uncued location. Thus, eye movements might have resulted in fixation at the uncued location, yielding the apparent location-based inhibition. We have already outlined one argument against this position. In this data set, all four subjects were tested in both the location- and color-based conditions. The pattern of results obtained with these additional subjects was similar to that of the original Experiment 2. In fact, the results were a bit simpler in that there was no interaction between location and color. Moreover, 4 of these subjects were tested in a different version of Experiment 2, in which they were required to move their eyes to the cued location and keep them there. We again found a similar pattern of results. These data undermine the eye-movement explanation of inhibition of return. These additional experiments will be reported more fully elsewhere.

5. We would like to thank Toby Mordkoff for pointing out the potential problems associated with luminance change.

6. Other investigators (Maylor, 1985; Posner & Cohen, 1984) used a cue stimulus different from the target stimulus in size and shape. Specifically, in Posner and Cohen's study, the cue was the brightening of a box much larger than the target (which was a small square), whereas in our Experiment 5, the cue and target were both small colored squares. Therefore, one might suppose that it was difficult for the sub-
jects to discriminate the target from the cue. We believe that the subjects did not experience this difficulty, however, because of the relatively long SOA levels (ranging from 700 to 1,300 msec) and the fact that the target remained present until the subject responded. This is supported by the fact that mean RT was well within 250 msec. In addition, we wanted to keep the stimuli the same as in Experiment 2 (except for the use of equiluminant stimuli) so that results from these experiments could be compared. Also, there was no explicit manipulation to draw subjects' attention back to the center location in Experiment 5. Posner and Cohen (1984) assigned a high probability (.6) of target presentation in the center location in order to keep subjects' attention at the center location most of the time. Maylor (1985) presented another cue at the center position after the presentation of the first cue. However, because identical results were obtained without these manipulations (Maylor, 1983; Maylor & Hockey, 1985), we did not try to draw our subjects' attention back to center position. We chose not to attempt this manipulation because a comparable manipulation is not feasible in the color domain. Also, the subjects would have had difficulty discriminating the target (third stimulus) from the second cue.

7. We have conducted additional experiments, to be reported elsewhere, that have eliminated still other explanations of inhibition of return. For example, all of the present experiments required a simple detection response. We have conducted experiments in which subjects made choice reactions (e.g., press one button for a red stimulus and another button for a blue stimulus). We again found inhibition of return based on location but not on color. It remains an interesting question for further research what the relation is, if any, between such a result and the "negative priming" effect reported by Tipper and his colleagues (e.g., Tipper, Brehaut, & Driver, 1990). Since negative priming can be found for attributes other than location, the two phenomena may differ fundamentally.

(Manuscript received September 9, 1991; revision accepted for publication December 26, 1991.)