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# Testing sensory and motor hypotheses of inhibition of return

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Simple reaction time to a luminance target may be lengthened when the target is preceded by a noninformative cue at the same location. This is known as inhibition of return, because attention is inhibited from returning to the locus of the first stimulus. Three experiments were carried to test several alternative explanations of inhibition of return. Using vertical stimulus arrays in Experiment 1 and employing a voice key in Experiment 2, we failed to obtain evidence for a motor explanation of the inhibition effect. Experiment 3 used response accuracy as a dependent measure and failed to obtain an inhibition effect. In conclusion, 1) eye movements and motor interference are not responsible for inhibition of return; 2) since inhibition of return is obtained only in a speeded RT task, a peripheral-sensory interference is not the cause of the inhibition effect. To accommodate these results, a revised model of inhibition of return was proposed.

One of the primary research topics of cognitive psychology is the study of the mechanisms of visual attention. Because there is virtually an infinite amount of information available to us, we must somehow select what is relevant and important to our needs. Therefore, examining the way the human visually selects aspects of the environment (e.g., a sudden flash of light or the color of an animal) and how the organism withdraws its effort from other aspects of the environment can be an important step in understanding vision. In this paper, I elucidate how people orient attention to aspects of the visual environment, and examine what the consequences are of orienting attention to the stimulus.

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 70% of the time (valid trials) and in each of three other locations 10% of the time (invalid trials), 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 thus provides no information to the participant, 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 ms) then RT is faster when the target is in the same location as the cue. However, for longer cue-target intervals, say from 300 ms to at least 1500 ms, RT is slower when the target appears in the same location as the cue (e.g., Maylor & Hockey, 1985; Posner & Cohen, 1984; Posner, Cohen, Choate, Hockey, & Maylor, 1984; Possamaï, 1986; Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987). This latter effect, known as inhibition of return, is the focus of this paper. In the paragraphs below, I review its empirical basis.

In Posner and Cohen's (1984) experiment participants were presented with three boxes, one to the left, one at the center, and one to the right on a screen. A trial began with brightening of one of the peripheral boxes for 150 ms, which served as a visual cue. A small dot that served as the target appeared in the center of one of the boxes 0 to 500 ms following the onset of the cue. The target appeared in the central box with probability .6 and in each of the peripheral boxes with probability .1. Catch trials (on which no target appeared) occurred with a probability of .2. Participants were required to press a key upon detection of the target (i.e., target discrimination was not required). When the cue preceded the target by up to 100 ms, mean RT for the detection of the target was faster 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 ms, RT to a target on the cued side was slower than one on the opposite side. Therefore, the early facilitation for targets on the cued side was replaced by a subsequent inhibition. This was called inhibition of return, because it was assumed that after being drawn to a peripheral location by the cue, attention returned to the center location and therefore had to go back to either side of the peripheral locations. This is plausible because 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 participants 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 (early facilitation and later inhibition) were unchanged when participants were cued by dimming the peripheral box rather than by brightening it. This result ruled out the explanation that the facilitative effect was 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 participants 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 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 presented 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 must 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 while 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 summon attention (e.g., peripheral cue onset) in order to get an inhibitory effect. Therefore, only exogenous orienting (e.g., peripheral cue) results in inhibition of return, whereas endogenous orienting (e.g., central cue) does not.

Finally, when both peripheral boxes were cued, the facilitation effect was diminished while the inhibition effect was, if anything, slightly increased. Assuming attention cannot be split between noncontiguous locations (Posner, et. al., 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 & 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 those 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, as it is also far from clear just how the relevant aspect of sensory information ultimately causes inhibition (for some possible mechanisms, see Possamaï, 1991; Tassinari et al., 1987).

While the facilitative effect of the non-informative cue was well explained by the summoning of attention to the cued location, the inhibition effect is less obviously explained. This is partly due to the fact that several conflicting results have been obtained (e.g., Posner & Cohen, 1984; Maylor, 1985). As a result of the search for the boundary conditions for obtaining the inhibition effect, three broad classes of hypothesis have emerged: the attentional, sensory, and motor hypotheses of inhibition of return (Maylor, 1985; Posner & Cohen, 1984; Possamaï, 1991; Tassinari, 1987).

## Attentional Hypothesis

The attentional hypothesis of inhibition of return assumes that inhibition of return is the consequence of orienting of attention to a spatial location (Maylor, 1985). As the term "inhibition of return" implies, according to the attentional hypothesis, once attention is oriented to a certain location and is subsequently withdrawn to another location, the tendency for the attentional system to return to the original location is inhibited, thus slowing down responses to stimuli at the original location.

Strong evidence for the attentional explanation of inhibition of return would be a demonstration that shows that the amount of inhibition of return depends on attentional orienting. Maylor (1985, Experiment 3), included a double-cue condition in which both the peripheral sides were cued, along with the conventional, single, valid-cue and invalid-cue conditions. Maylor reasoned that, if participants randomly choose one position to orient attention to in the double-cue condition, half of the double-cue trials are functionally equivalent to the single, valid-cue condition which is supposedly responsible for the inhibition of return, whereas another half of the double-cue trials are equivalent to the invalid-cue condition which is assumed to have no inhibition effect. If inhibition arises from the single, valid-cue condition, the double-cue condition would show less inhibition effect because it represents a mixture of inhibition and no-inhibition trials. As predicted, the amount of inhibition of return in the double-cue condition was reduced by half compared to the single, valid-cue condition, supporting the notion of attentional orienting. However, as Maylor admitted, the RT distribution of the double-cue condition did not show a significant indication of bimodality (see Yantis, Meyer, & Smith, 1991 for a detailed discussion of the mixed analysis).

However, not all attentional orienting causes inhibition of return. 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 while 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 summon attention (e.g., a peripheral, abrupt onset cue) in order to observe an inhibitory effect.

## Sensory Hypothesis

According to the sensory hypothesis (Posner & Cohen, 1984), attentional orienting is neither necessary nor sufficient for obtaining inhibition of return. Instead, inhibition of return is simply due to energy change or sensory stimulation at a cued location. As stated above, the use of a symbolic (arrow) cue failed to produce inhibition of return (Posner & Cohen, 1984), suggesting that attentional orienting is not a sufficient condition for inhibition to occur.

Stronger evidence for the sensory hypothesis was obtained by Posner & Cohen (1984). When both peripheral boxes were cued, the facilitation effect was diminished while the inhibition effect was, if anything, slightly increased. Assuming attention cannot be split between noncontiguous locations (Posner et. al., 1980; but see Cave & Pashler, 1990), this double-cue effect suggests that the inhibition does not arise from attentional orienting but from the sensory information due to energy change present at the cued position (Posner & Cohen, 1984). However, it is far from clear what aspect of sensory information is responsible for the inhibition, as it is also far from clear just how the relevant aspect of sensory information ultimately causes inhibition. For example, the sensory hypothesis may have difficulty explaining why inhibition of return is obtainable only with locations, but not with any other stimulus attributes such as color or orientation.

Another prediction from the sensory hypothesis stems from the fact that if sensory processing is responsible for the inhibition effect, then it should be revealed in a task using a different dependent measure. Since it was suggested that the use of accuracy as a dependent variable usually reveals early perceptual processing more sensitively than the use of reaction time (Santee & Egeth, 1982), a sensory hypothesis predicts inhibition effect in a briefly presented display with an accuracy task. Therefore, in Experiment 3, using an accuracy dependent measure, we test predictions of a sensory hypothesis.

## Motor Hypothesis

A simple version of the motor hypothesis of inhibition of return rests on the fact that participants must inhibit responding to the cue stimulus. If the cue is presented at the same position as the target, inhibition to responding to the cue would be more easily transferred to responding to target. Therefore, the interference in the motor system would result in an inhibition effect. However, this hypothesis was rejected by Maylor & Hockey (1985). Maylor and Hockey (1985) found an inhibitory effect in a paradigm that required participants 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 was manipulated from trial to trial. Since participants respond to every stimulus presented, inhibition of response to stimuli is not needed. Even in this paradigm, however, responding to a target presented at the same location as the previous target is slower than to a target at the opposite location. Thus inhibition cannot be attributed to the inhibition of a motor response to the cue, thus discounting the simple motor hypothesis.

Investigators have argued that inhibition of return may be due to the system which is related to the control of eye movements (e.g., Rafal, Calabresi, Brennan & Sciolto, 1989, Abrams & Dobkin, 1994). Specifically, upon the presentation of a visual cue, participants' attentional system automatically orients to the cued position and prepares their saccadic eye-movement system to move to the cued position. However, since participants are instructed prevent eye movements to the cued side, an inhibitory mechanism would have to be activated to inhibit eye movements. When the target is presented at the cued position, participants' tendency to inhibit the cued-side motor system may result in a slowed response to the target. It is predicted that inhibition of return would be obtained whenever saccadic preparation is induced and the oculomotor system is activated.

Other forms of motor explanation of the inhibition effect postulate that the presentation of a visual cue either to the left or right of fixation will automatically activate and prime eye-movement and hand-motor systems corresponding to the cued side (Tassinari, Aglioti, Chelazzi, Marzi & Berlucchi, 1987). Since participants would have to prevent responding to the cue, an inhibitory mechanism must be activated to inhibit the motor pathway which controls button pressing on the cued side, resulting in inhibition effects. In other words, participants avoid saccadic eye-movements by generating a motor instruction that counteracts the orienting eye reaction, which has the effect of biasing the entire motor system against reacting to stimuli in that direction. Therefore, the directional conflict between maintenance of fixation and the execution of the manual response would result in inhibition of return. It can be predicted that if the stimulus configuration does not match right/left-handedness, then the net inhibition effect would be decreased. Also, if the use of left/right responding is abolished, the inhibition effect would be reduced, if not eliminated. These predictions will be tested in Experiments 1 and 2.

While Experiments 1 and 2 employed only a cue-target paradigm, the motor explanation mentioned above also applies to a continuous responding paradigm. The reason is that, according to the latter version of motor explanation, the inhibition effect is not merely the result of suppression of response to cue stimuli, but that of directional conflict between eye-movement commands and hand-motor commands. Therefore, unless the left/right directionality or the interactions between the two systems is eliminated, the possibility of inhibition effect will always be remained.

## Experiments 1 and 2: testing motor hypothesis of inhibition of return

As mentioned above, one form of motor explanation of inhibition effect assumes that the presentation of a visual cue either to the left of right of the fixation will automatically activate the eye-movement and hand-motor system corresponding to the cued side, and the directional conflict between these two activations results in an inhibition effect (Tassinari et. al., 1987).

To test these variants of motor explanation of inhibition effect, Experiment 1 presented participants with vertical array of cue and target displays in a cue-target paradigm. Specifically, a cue was the brightening of an outline box which was either above or below the fixation point, and the target was the presentation of a small square at the center of one of the boxes. If inhibition of return is somehow related to the motor system which is responsible for controlling right/left-hand responses, then the magnitude of the inhibition effect should be reduced compared to earlier experiments using right/left stimulus configurations. The reason is simply that stimuli above or below fixation should not create as strongly lateralized an activation as stimuli presented left or right of fixation.

In Experiment 2, the use of the hand-response system was completely eliminated by employing a voice key instead of a button-press key. The use of the vocal RT task would minimize the competition between eye movement system and hand-response motor system. If inhibition effect is due to the motor processing, then the use of voice key would result in the reduced amount of inhibition effect.

## Method

**Participants.** Ten participants participated in Experiment 1 in a single session. Another seven participants participated in Experiment 2 in a different session. All had normal or corrected-to-normal vision.

**Stimuli.** In Experiment 1, a fixation display consists of .25 deg of a central '+' sign and two (above, below the fixation "+") gray boxes with the size of 1.4 x 1.4 deg each (see Figure 1 for an example display). In Experiment 2, the two peripheral gray box were placed at the right and left of the fixation "+". Distance between these two gray boxes and central fixation was 4.6 deg.

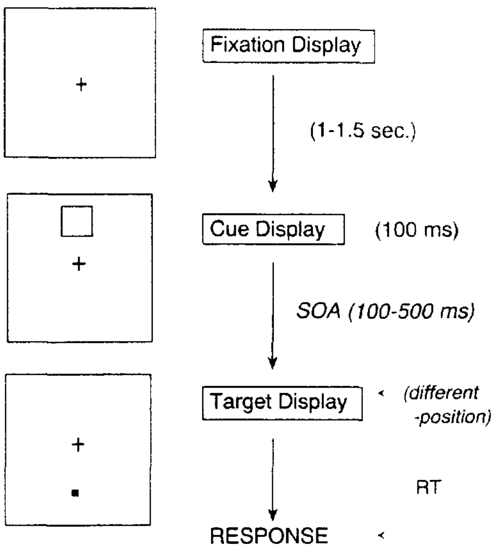


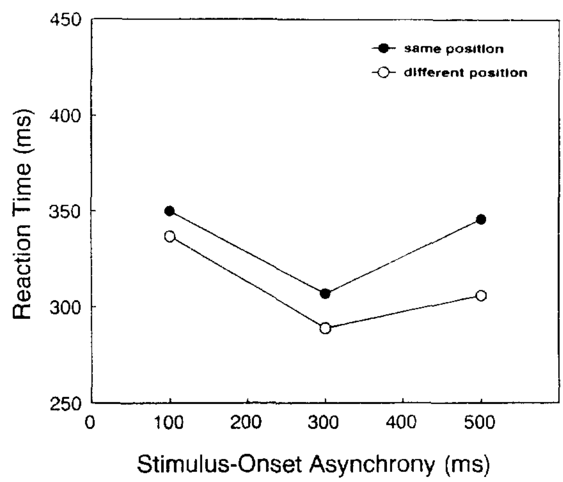

**Figure 1.** Stimulus display example and procedure used in Experiment 1.

Each target was .12 x .12 deg of white square appeared at the center of one of the peripheral boxes. The cue was the brightening of one of the peripheral boxes. The probability of the target on the cued side was the same as that on the uncued side, so that the cue was uninformative regarding target positions.

Procedures. In both Experiments 1 and 2, a trial began with presenting a central fixation "+" with two outline boxes for .8 to 1.3 sec. The fixation display was replaced by a cue display which is brightening of one box for 150 ms and followed after a variable SOA, ranging 100 ms to 500 ms, by the target display in which a small square was presented in one of the peripheral boxes. Participants in Experiment 1 were required to press a button as quickly as possible upon the presentation of a target in one of the peripheral boxes. Using a voice key, participants in Experiment 2 made a vocal response (a "poe" sound) upon the presentation of a target.

Designs. In both Experiments 1 and 2, combinations of two positions and three levels of SOA (100, 300, and 500 ms) were manipulated, resulting in a 2 (same vs. different position) x 3 (SOAs) repeated-measures design. Each participant in both experiments was presented with ten blocks of 32 trials.

## Results and Discussion




**Figrure 2.** Mean reaction time as a function of Stimulus-Onset Asynchrony (SOA), and Position in Experiment 1.

Figure 2 shows mean RT for each condition in Experiment 1. A two-way repeated-measures analysis of variance was conducted on the mean RTs. There was a significant effect of position, $F(1,9) = 34.09$, $p < .001$, and of SOA, $F(2,18) = 28.28$, $p < .001$, and of the interaction between position and SOA, $F(2,18) = 9.08$, $p < .01$. Inspection of Figure 2 shows that the interaction is due to the fact that inhibition of return increases as SOA increases.

There was no indication of facilitation effect of cue at the shortest level of SOA. This lack of facilitation at SOA 100 ms was unexpected, given that Posner & Cohen (1984) obtained a facilitatory effect in the short SOA range. While the reason for the lack of facilitation effect is not clear, some other investigators also have reported similar pattern of results (Possamaï, 1991).

More important is the finding in Experiment 1 that a substantial amount of inhibition effect (40 ms) was obtained at 500 ms SOA. Since it was hypothesized that the vertical configuration of cue-target position would minimize the response conflict between eye-movement motor system and finger-hand movement system, the reduced amount of inhibition compared to the results of earlier experiments (e.g., Kwak & Egeth, 1991) that employed left/right array of stimuli was predicted. Therefore, it can be suggested that the locus of inhibition effect is not in the motor level, or in the eye-hand coordinate system.

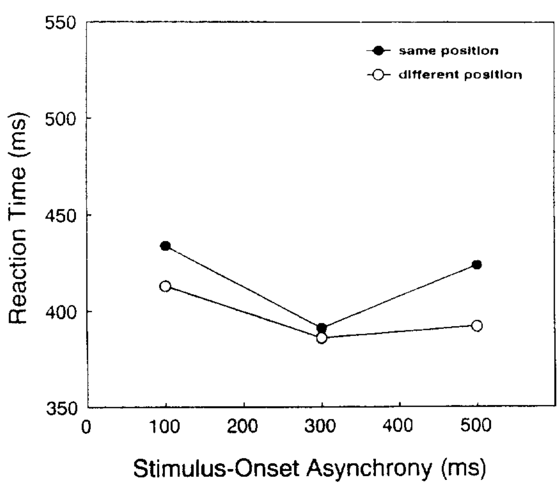



**Figure 3.** Mean reaction time as a function of Stimulus-Onset Asynchrony (SOA) and Position in Experiment 2.

Mean RTs for each condition in Experiment 2 are presented in Figure 3. A two-way repeated-measures analysis of variance for the mean RTs indicated a significant effect of position, $F(1,6) = 37.41$, $p < .01$, and of SOA, $F(2,12) = 7.13$, $p < .01$. Overall, the pattern of results in Experiment 2 is similar to that of Experiment 1, suggesting that switching from a button press response to a vocal response did not change the pattern of results critically. Again, it can be concluded that inhibition of a lateralized motor system is not responsible for inhibition of return.

## Experiment 3: testing a sensory hypothesis of inhibition of return

All of the existing evidence for inhibition effects come from tasks requiring speeded responses, and the index of the effect has been a relative increase of RT to targets in the cued location compared to the uncued location(s). However, it is not clear whether the inhibition effect is due to the time needed for re-orienting attention to the cued location, or due to the time needed for extracting information from the location, or due to the time needed for selecting and executing a response.

According to a sensory explanation of the inhibition effect, the effect should also be revealed by dependent measures other than response time. Specifically, if the inhibition effect is due to delayed information extraction, or suppression of a location, then the effect should also be obtained using accuracy as a dependent measure (see Hillyard, Luck, Mouloua, Downing, & Woodward, 1990, for discussions of an accuracy measurement of visual-spatial attention). On the other hand, if there is no inhibition effect in an accuracy task, the model that can explain the result may be more likely based on response-related processes (Santee & Egeth, 1982).

In Experiment 3, participants were presented with a rotated T or L (e.g., Kwak, Dagenbach, Egeth, 1991; Egeth & Dagenbach, 1991; Folk, Egeth, & Kwak, 1988), which was briefly presented after a visual cue, and were required to determine the identity of the target letter.

# Method

**Participants.** Eight undergraduate students at The Johns Hopkins University participated in Experiment 3 as a requirement for a introductory psychology course.

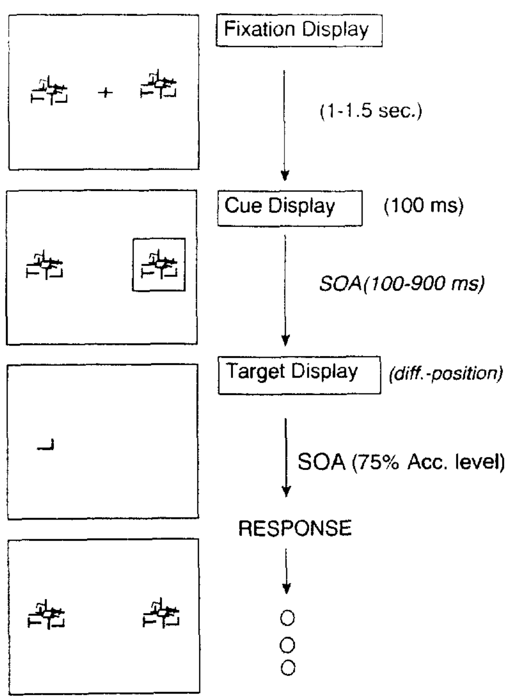



**Figure 4.** Stimulus display example and procedure used in Experiment 3.

**Stimuli and Apparatus.** A fixation display consists of a central '+' sign with three gray boxes at the center, and 4.6 deg left and right of the fixation point (see Figure 4). Each of the two peripheral boxes in the fixation display contains pre-mask which is made of random superpositions of Ts and Ls inside the gray box. A cue was the brightening of one of the peripheral outline boxes (the masking stimulus inside the box was not brightened). The target letter was either rotated (0, 90, 180, and 270 deg.) T or L, which was presented inside of one of the two peripheral boxes. The size of the target was .8 x .8 deg in visual angle. An Eye-Trac eye movement monitoring device was used to monitor participants' eye movements during trials.

**Procedures.** Each trial began with presenting a fixation display for 1-1.5 sec, which was replaced by a cue display by brightening of one of the peripheral boxes. The cue was presented for 100 ms, followed after a variable SOA, ranging from 100 ms to 900 ms, by the target display and was replaced by a postmask display. Participants were required to determine which letter was presented briefly by pressing a button. They were told not to move their eyes during trials, and any trial indicating the halfway movement to the target was considered as error and was deleted from subsequent analysis. The speed of the response was not stressed. The exposure duration for the target display was set in the practice block so that the overall accuracy would be around 75%.

**Designs.** Combinations of two locations (right and left) and three levels of SOA (100, 500, and 900 ms) were manipulated, resulting in a 2 (same/different position) x 3 (SOAs) two-way repeated-measures design. There were five blocks of 96 trials for each participant.

## Results and Discussion

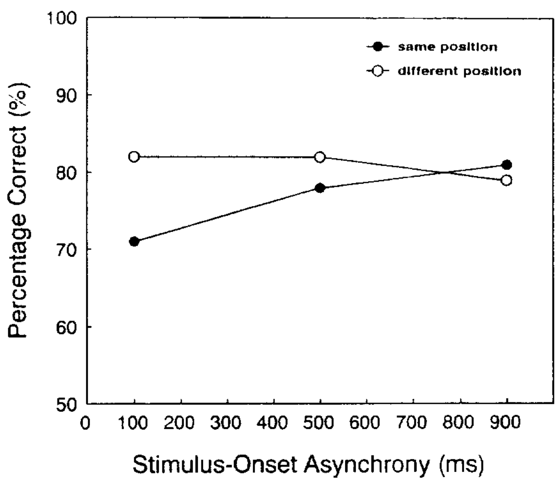



**Figure 5.** Mean percentage correct as a function of Stimulus-Onset Asynchrony(SOA) and Position in Experiment 3.

Mean percentage correct for each condition in Experiment 3 is presented in Figure 5. A two-way analysis of variance for the accuracy data indicated a significant effect of position, $F(1,7) = 56.32$, $p < .001$, and of SOA, $F(2,14) = 4.62$, $p < .05$, and of their interaction, $F(2,14) = 9.74$, $p < .01$. Inspection of Figure 5 indicates the effect of position is due to detrimental effect (71% for same-position, and 82% for different-position) of position at the SOA level of 100 ms (i.e., inhibitory effect of position), and the position-SOA interaction is due to the decreasing trend of that inhibitory effect of position as SOA increases. This pattern of results was unexpected, since it was predicted that the accuracy of the same-position would be better than that of the different-position at the shortest level of SOA due to orienting of attention. It is possible that the presentation of a visual cue (i.e., brightening of one of the peripheral boxes) may have masked the subsequent target detection at the cued side.

In any case, there was no indication of inhibition effect at the SOA level of 500 ms and 900 ms (80% for same-position and 81% for different-position). These results are inconsistent with the prediction of a sensory explanation of the inhibition effect. Apparently, a change from a speeded-reaction time task to an accuracy task may have caused the inhibition effect to disappear. Therefore, it can be suggested that the inhibition effect may be confined to the tasks requiring participants speeded responses. That is, as Maylor (1985) argued, "... inhibition is a response-related process - that is, it reflects a reluctance to respond rapidly to a stimulus appearing in the same peripheral location as a previous one that produced orienting...(Maylor, 1985, pp. 202)".

The lack of inhibition effect at long SOA levels in Experiments 3 suggests that a sensory explanation may not be a viable hypothesis for inhibition effect. Instead, more plausible hypotheses of inhibition effect may be found in models with response-related process.

## General Discussion

The major purpose of the research was to examine several alternative hypotheses of the origin of inhibition effect. Experiments 1 and 2 tested a variant of the motor explanation of the inhibition effect. Using vertical configuration of stimuli in Experiment 1, and introducing a voice-key response task in Experiment 2, both experiments failed to find evidence for the motor hypothesis of inhibition effect. The pattern of the inhibition effect was not affected by stimulus configurations or by response devices.

Experiment 3, employing accuracy as a dependent measure, failed to find inhibition of return in response accuracy. The lack of inhibition effect in accuracy suggests that the inhibition effect may be a response-related effect. In other words, the effect may only be revealed in a speeded reaction task.

From the results of experiments 1, 2, and 3, it can be concluded that; (1) a simple motor hypothesis cannot explain (a) the lack of color- or orientation-based inhibition effect(Kwak & Egeth, 1991), (b) the fact that inhibition effect was not affected by stimulus configuration or by the use of voice reaction task; (2) a sensory hypothesis cannot explain (a) the fact that there was no indication of the inhibition effect in an accuracy task, (b) the lack of color- or orientation-based inhibition. While none of these two models could explain all the patterns of results obtained here, a revised version of the attentional hypotheses may be the most viable model to explain the inhibition effect.

## A model of Inhibition of Return

The results of Experiments 1-3 suggests that none of the two models of inhibition effect (motor and sensory hypotheses) can fully explain the observed results. It is not clear whether we could find an entirely different hypothesis that could explain all of the results obtained. Among the three models, however, the attentional hypothesis may be the one that could be revised relatively easily to explain the conflicting results. It should be noted that the other two models could also be revised, however, even though it is not clear how it could be done easily. Since this paper is about orienting of attention to locations and to features and their consequences, I will focus on revising the attentional hypothesis.

Several assumptions must be made in order for the attentional model to explain the results obtained here. First, it must be assumed that externally controlled attention generates inhibitory tags across the visual field, so that several places can have inhibitory tags at one time (See Klein, 1988 for detailed discussion of the inhibitory tagging mechanism). This assumption is needed to explain the double-cue results. Second, it must be assumed that the tags can affect processing speed, but not accuracy, since the inhibition effect was not obtained in an accuracy task. In other words, the rate of the accumulation of response force is affected by the inhibitory tagging, but the quality of information is not affected by the inhibitory tagging (See Santee & Egeth, 1982, for the comparison of RT and accuracy as dependent measures). Finally, the attentional hypothesis must somehow incorporate some aspects of both the sensory and the motor hypothesis. Specifically, the inhibitory tagging mechanism may partially overlap with a certain sensory (color) pathway, since there was an interaction between the inhibition effect and color(Kwak, 1992). Also, since eye movement instructions altered the pattern of inhibition effects, it is possible that the inhibitory tagging mechanism shares a certain pathway with the eye movement control system(Abrams & Dobkin, 1994).

From the revised version of the attentional hypothesis, several interesting questions can be asked. First, would the same inhibition effect be obtained if more than two locations were cued? This question is related to the inhibitory tagging mechanism that Klein (1988) proposed. According to the hypothesis, the inhibition effect must be obtained throughout a reasonable range of the number of tag locations. Second, if several objects in the visual field are randomly moving, would the center of inhibition effect be moved along with the cued-object or stay at an absolute location(Gibson & Egeth, 1994a; 1994b; Tipper, Weaver, Jerreat, & Burak, 1994)? If the inhibitory tagging system is tied to an absolute coordinate system, the inhibition effect must be abolished. Since it is generally assumed that visual attention is tied to visual objects (Duncan, 1984; Treisman, Kahneman, & Burkell, 1983), not to absolute locations, we should obtain inhibition effect through object-defined locations. Third, if attentional inhibitory tagging affects the speed of responding only, would the inhibition be revealed by criterion change rather than sensitivity difference when data are analyzed by the signal detection theory (e.g., Hillyard et. al., 1990)? This question could test whether the loci of inhibition effect is at a response level, or at an early perceptual level.

## Ecological significance of inhibition of return

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 participants search for a conjunctively-defined target, which presumably requires a serial search of the display (Treisman & Gelade, 1980). On half of the trials, 60 ms after responding to the conjunctive target (and, thus, about 700 ms - 1800 ms 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. They reasoned that if inhibition of return operates in visual search to increase sampling efficiency, then participants 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 visual search tasks. Further research is needed to solve these conflicting results.

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# 회귀억제에 관한 감각가설 및 운동가설의 검증

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시각장의 특정 위치에 비정보적인 말초단서를 제시하고 일정시간(예: 1초)이 지난 후에 밝은 점으로 된 표적을 제시하면 그 표적에 단순반응시간은 다른 위치에 제시된 표적반응시간보다 느려진다. 이 현상을 회귀억제라 하는데, 왜냐하면 주의는 단서가 제시된 위치로 회귀하는 것이 억제되었기 때문이다. 세 실험이 회귀억제에 대한 몇가지 상대가설을 검증하기 위해 실행되었다. 실험 1에서 수직적인 자극배열로서, 그리고 실험 2에서 발성키를 사용하여 자극과 손운동의 방향성을 통제한 상황에서도 회귀억제가 얻어졌으므로 운동가설이 기각되었다. 실험 3에서는 정반응률을 종속측정치로 사용하였는데, 회귀억제효과가 얻어지지 않았으므로 감각가설이 기각되었다. 결론적으로, 1) 안구운동이나 운동간섭이 회귀억제 효과를 설명할 수 없다; 2) 회귀억제는 속도를 중시하는 반응시간과제에서만 얻어지므로 초기 말초·감각 수준에서 회귀억제를 설명할 수 없다. 이러한 결과들을 바탕으로 수정된 회귀억제의 모형이 제안되었다.