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The effects of memory load on the time course of inhibition of return

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Inhibition of return (IOR) refers to a processing disadvantage at a recently attended location. It is generally agreed that when elicited in a cue–target task, IOR will not be apparent until attention is disengaged from the originally cued location and returned to a neutral state. Here we test the hypothesis that when such disengagement is dependent on endogenous control, a secondary task that taxes working memory capacity should delay the appearance of IOR. Participants were given a six-item verbal working memory load prior to the peripheral cue in a cue–target detection task. Consistent with the hypothesis, the appearance of IOR was delayed on trials for which participants had to hold information in working memory. Converging evidence was derived from a second experiment in which the time course of IOR's appearance, when we added a central cue to exogenously remove attention from the peripheral cue, was unaffected by the memory load.

Inhibition of return (IOR) was first reported and thoroughly characterized by Posner and Cohen (1984). Simply put, whereas the immediate effect of an uninformative peripheral cue is the facilitation of processing in the vicinity of the cue, later processing is inhibited. IOR has garnered considerable interest recently (for a review, see Klein, 2000), no doubt because evidence is growing to support the following functional attribution: IOR encourages orienting toward novel objects and regions of space (Posner & Cohen, 1984) and by doing so facilitates foraging behaviors (Klein, 1988; Klein & MacInnes, 1999).

A standard explanation for the biphasic pattern of performance is the following sequence of mental states: (1) Initially attention is in a neutral state, centered at fixation and equally primed for stimuli to appear in the possible target locations; (2) immediately following the appearance of a cue (an uninformative peripheral event), attention is captured by the cue and stimuli presented in the vicinity of the cue benefit from the proximity of attention while those presented away suffer; (3) after some time attention goes back to a neutral state, and, as attention is removed from the location of its initial capture by the cue, (4) an inhibitory aftereffect of the cue is seen to delay processing of stimuli subsequently presented there, possibly by an inhibitory effect upon attention itself.

In their original experiments, Posner and Cohen (1984) used two methods to ensure that attention did not remain at the cued location (3): (1) They made the center target more likely than targets at either of the two peripheral locations, thus providing the impetus for participants to endogenously disengage their attention from the peripheral cue and reorient it back to the central (fixated) locations. Or, (2) they presented a second cue at fixation to draw attention back there exogenously. Many of the 150 or so studies of IOR that have followed Posner and Cohen's seminal contribution have used neither of these procedures, so it is clear that IOR can be found both with and without a fixation cue. In this study, we are interested in the time course of the appearance[1] of IOR, and we will test the proposal that without the fixation cue, this depends, at least in part, on endogenous disengagement from the peripheral cue and return of attention to a neutral state.

When the return of attention to "neutral" is left to the devices of the observer, what is the time course of IOR's appearance? Lupiáñez, Milán, Tornay, Madrid, and Tudela (1997) were the first to systematically explore this question. Like Posner and Cohen (1984), they found that when

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the observer's task was simple detection, IOR appeared from 200 to 300 msec following the onset of the cue. Merely changing the task to a two-choice discrimination delayed the appearance of IOR to 400–700 msec following onset of the cue. Klein (2000) explained these and other time course findings (Briand, Larrison, & Sereno, 2000; Lupiáñez & Milliken, 1999) with reference to the concept of an attentional control setting (Folk, Remington, & Johnston, 1992). Under this view, the degree to which attention is captured by the cue depends on the attentional control setting that is put in place to perform the target task. One factor that might affect this control setting (see Klein, 2000, pp. 141–142, for another factor) is the degree to which attention is required to perform the target task. When the processing of a target leading from stimulus to response is demanding, the observer is prepared to intensely attend to the target. Because rapid switching of attentional control settings is difficult, processing of the cue will be subject to the controls in place for the target. Thus, attention will be more strongly captured by cues when target processing demands are high. This, in turn, delays the disengagement of attention, which leads to the delayed appearance of IOR. For our present purposes, the key idea in this proposal is that IOR may not be observed until attention is disengaged from the cue and returned to neutral.

In the example above, the time course of IOR varies, in normal adults, with the nature of the target processing needed in order to perform the task. Several studies of individuals who are not normal young adults have shown no evidence of IOR or delayed IOR (see Klein, 2005, for a review). In comparison with normal young adults, and when no central cue is used to exogenously return attention to fixation, schizophrenics (Huey & Wexler, 1994; Sapir, Henik, Dobrusin, & Hochman, 2001) and the elderly (Brodeur & Enns, 1997; Castel, Chasteen, Scialfa, & Pratt, 2003) show a substantial delay in the appearance of IOR, and young children do not seem to show IOR at all (Brodeur & Enns, 1997; MacPherson, Klein, & Moore, 2003), at least not within 1 sec of cue onset. In comparison with normal young adults, each of these groups is thought to be somewhat deficient in executive control of behavior. Klein (2005), therefore, proposed that these differences in the time course of IOR may be attributed to deficiencies in the anterior attention system, a frontal network responsible in part for the endogenous control of attention (see also Faust & Balota, 1997). This deficiency results in a failure to rapidly disengage attention[2] from the peripheral cue in order to be optimally prepared for a target at either peripheral location. Consequently, when the return of attention is controlled endogenously and when the anterior attention system is insufficiently developed or otherwise underresourced, the appearance of IOR should be delayed or absent.

EXPERIMENT 1

Following a strategy used by Jonides (1981), Roberts, Hager, and Heron (1994), and others, we used a verbal working memory load just *before* the cue in order to test this idea. In the presence of such a memory load, the onset of IOR should be delayed, because the memory load would interfere with the endogenously controlled disengagement from the peripheral cue. We chose to manipulate verbal rather than spatial working memory because Castel, Pratt, and Craik (2003) had recently demonstrated that IOR was interfered with by a spatial but not a verbal working memory load presented after the cue. Hence, if we obtained the predicted effect of the verbal working memory load, we could have some confidence that the load was having its effect on cue-related processing because, when delivered after the cue, the same kind of load had no effect on IOR.

Method

Participants. Forty-four undergraduate students from the University of Toronto participated in the experiment in return for course credit. All had normal or corrected-to-normal vision and were naive with regard to the purpose of the experiment.

Apparatus and Procedure. The experiment took place in a dimly lit sound-attenuated room. The participants were seated 44 cm in front of a computer monitor. The viewing distance was held constant with the use of an adjustable head/chinrest, and the computer keyboard was placed directly in front of the participants.

The sequence of events is shown in Figure 1. The participants were told that they would participate in two conditions, one of which would require remembering digits and responding to targets, and one that would require simply responding to targets. They were told to respond as quickly and as accurately as possible, and to place an equal emphasis on the memory task and the detection task.

The initial display was presented for 500 msec. It included two placeholder boxes located on the horizontal meridian to the left and right of the fixation point. The boxes were centered 5º from the fixation point and were 1º square, and the fixation point had a diameter of 0.2º. In the memory load condition, six random numbers (from 1 to 9) were then presented consecutively at the central fixation point. Each number appeared for 300 msec, followed by a 150-msec delay, followed by the next number. In the no-load condition, six consecutive number sign symbols (#) were presented in the same manner as were the numbers. In both conditions, following the presentation of the last digit or number sign symbol, there was either a 150- or 500-msec delay before the fixation point reappeared (remaining present for the remainder of the trial) while one of the two peripheral boxes was cued by outlining the perimeter of the box for 50 msec. After a variable stimulus onset asynchrony (SOA) of 100, 200, 400, or 800 msec, a white target circle (0.7º) appeared in one of the two boxes (on 80% of the trials; the remaining 20% served as catch trials in which no target was presented). The participants were asked to respond to the target as quickly and as accurately as possible by pressing the space bar (regardless of the location of the target), and to remain fixated throughout each trial. A 400-Hz tone was presented for 100 msec if the participant failed to respond within 1,000 msec of the onset of the target, or if they responded on catch trials. Following the detection response in the memory load condition, the participants were asked to recall (in the correct sequence) the six numbers that appeared prior to the cue. The participants entered the numbers using the numeric keypad, and the next trial began 1,000 msec after the last digit was entered. The participants had up to 3 sec to recall and enter each digit, and they heard a 400-Hz tone if their overall response was incorrect. In the no-load condition, the next trial began 1,000 msec after the participant's response to the target on noncatch trials.

Design. The delay between onset of the last digit (or number sign, in the no-load condition) and the appearance of the cue was a between-subjects variable. Twenty-two participants experienced the 150-msec delay; the remaining 22 participants experienced the 500-msec delay. Memory load (six digits vs. no load) was a within-

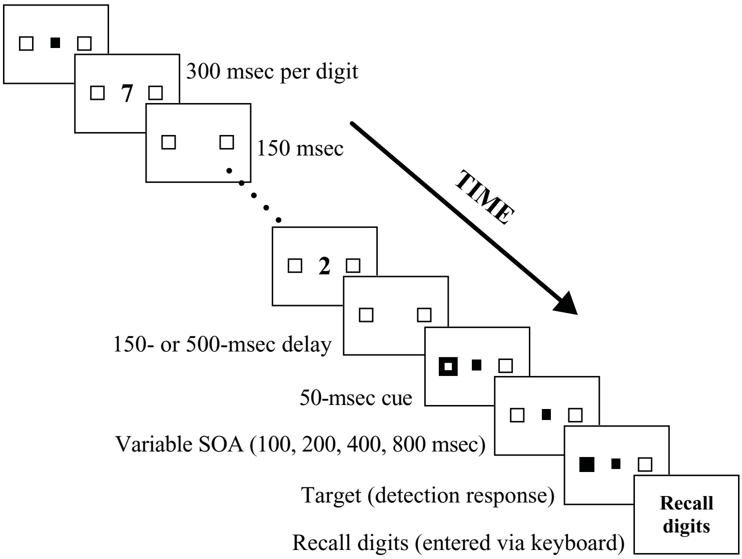

Figure 1. Sequence of events in a given noncatch trial in the memory load condition in the present experiment. (Stimuli, not drawn to scale here, are shown as black on white, but were actually presented in white on a black background).

subjects factor that was varied between blocks. The order of the conditions was counterbalanced across participants, in a single 90-min session. Each condition consisted of 180 trials, with cues and targets being equally likely to occur at the left and right locations. The participants were given a short break after 90 trials in each condition, as well as a break between the conditions, in which instructions were given about the second block.

Results and Discussion

Recall on the load trials was scored as correct when all six digits were recalled in the correct order and incorrect otherwise. The overall recall accuracy was 74.4%, with a large range from 96.5% to 30.6%.

The rate of responding on catch trials was 4.15% overall. Participants were highly successful at withholding responding in the no-load condition (false alarm rate = 0.3%), and they made significantly more false alarms in the load condition (false alarm rate = 8.0%) [$t(43) = 7.34, p < .01$]. The rate of anticipatory responses was less than 1%. Misses (failures to respond to targets within the 1 sec allowed) were also relatively infrequent, but there were nevertheless significantly more misses in the load condition (2.7%) than in the no-load condition (1.1%) [$t(43) = 3.8, p < .01$]. The increased rate of false alarms and misses in the load condition provides converging evidence that the load manipulation did indeed interfere with executive control. The reaction time (RT) data (upper panels of Figure 2) were subjected to an ANOVA with SOA, cue condition, and load as within-subjects variables and delay as a between-subjects factor. There were significant main effects of load [$F(1,42) = 58.48, p < .01$] and SOA [$F(3,136) = 19.43, p < .01$]. In the load condition, RT was 70 msec slower than in the no-load condition. The main effect of SOA reflects a typical warning signal effect, with RT decreasing as SOA increased, reaching a minimum at the 400-msec SOA and then increasing slightly. SOA interacted significantly with load [$F(3,126) = 5.33, p < .01$] and delay [$F(3,126) = 3.96, p < .01$], because the warning signal effect was muted when the delay was long (no doubt because the delay provided an opportunity to get prepared to respond) and when there was no load. The typical biphasic pattern of early facilitation and later inhibition of return was found as the critical interaction between SOA and cue condition was significant [$F(3,126) = 14.91, p < .01$]. The interaction between load and cue condition was significant [$F(1,42) = 5.1, p < .05$]. Collapsed across SOA there was a net inhibition in the no-load condition (5.7 msec) and a net facilitation (3.5 msec) in the load condition. No other effects or interactions were significant.

To determine whether a cuing effect was present, one-tailed *t* tests were performed on cued versus uncued RT for each combination of SOA and load.[3] With the exception of the two combinations marked by ellipses, all the cuing effects were significant. The important findings are apparent in the bottom panels of Figure 2, where RT in the uncued condition is subtracted from that in the cued condition to provide a single cuing effect score for each SOA by condition combination. In both load conditions, there was significant facilitation 100 msec after the cue. At 200 msec, the facilitation was no longer significant in the no-load condition but it remained significant in the load condition. Conversely, at 400-msec postcue, there was significant IOR in the no-load condition but the cuing effect in the load condition was not significant. Finally, at 800 msec, IOR was significant in both load conditions.

To determine whether the pattern of results in the load condition was somehow dependent on recall performance, participants were divided (median split) into those with good and those with poor memory performance. Both sub-

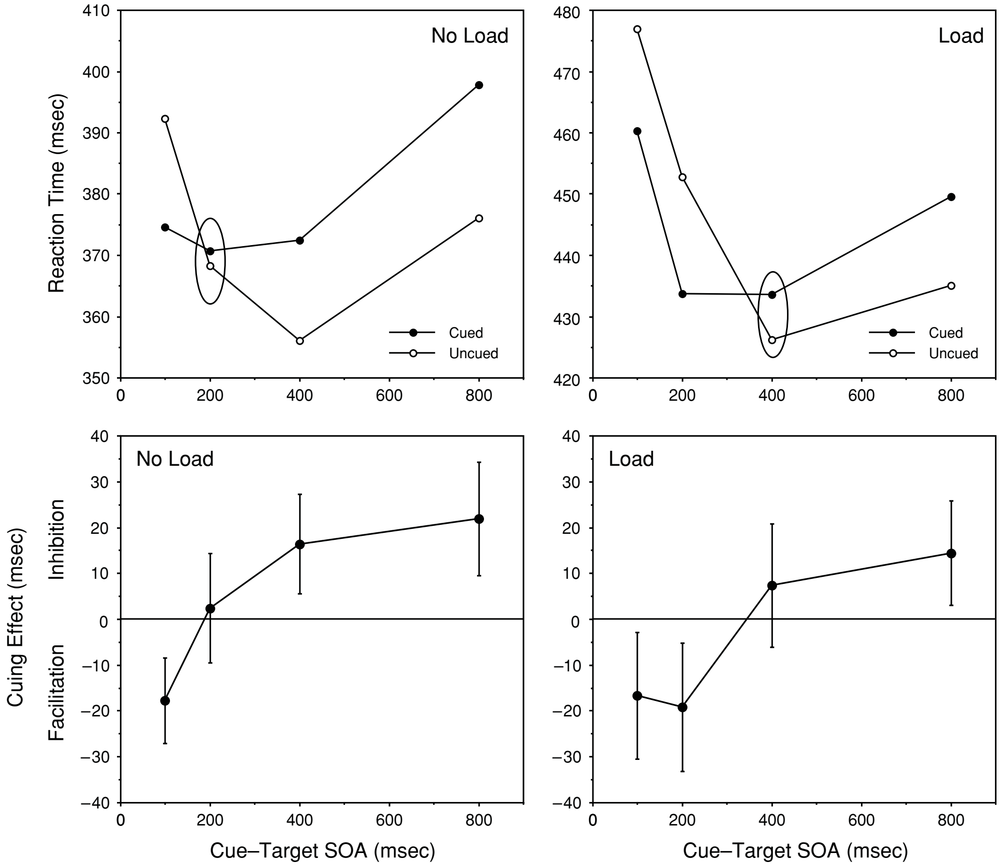

Figure 2. The reaction time (RT) results from Experiment 1. The upper panels show RT in the cued and uncued conditions, and the lower panels show the cuing effect (cued RT minus uncued RT), both as a function of cue–target SOA. Data from the no-load condition are shown in the left panels; data from the load condition are shown in the right panels. Ellipses in the upper panels show the two conditions in which one-tailed *t* tests did not reveal a significant difference between the cued and uncued RTs. All other differences were significant ($p < .05$). Ninety-five percent between-subjects confidence intervals are shown in the lower panels.

groups showed the same pattern, as can be seen in the right panels of Figure 2: facilitation at the two shorter SOAs, with a crossover to inhibition at the longer SOAs. It appears that whether or not a participant is trying to remember items held in working memory is what affects when IOR appears, not how well they remember these items.

As predicted by our theory that the appearance of IOR will depend on when attention is disengaged and moved from the cued location, in the presence of a verbal memory load the appearance of IOR was delayed. Our explanation of this effect depends on the idea that the return of attention in Experiment 1 was a voluntary act of endogenous orienting that is interfered with by the verbal working memory load (Jonides, 1981). The purpose of Experiment 2 was to obtain converging evidence for this explanation.

EXPERIMENT 2

Jonides (1981) demonstrated that a verbal working memory load interfered with endogenous but not exogenous orienting. Therefore, we could attempt to disconfirm our theory by adding a return cue to fixation between the peripheral cue and the target. If the working memory load in Experiment 1 was having its effect on the time course of IOR through a mechanism other than that previously proposed, then the time course difference apparent in Figure 2 should be maintained. On the other hand, if, as we proposed, placing a substantial load on working memory would delay the endogenous return of attention, then, when attention was rapidly and exogenously returned by a cue at fixation, there would be no effect of load upon the time course of the appearance of IOR.

Method

The methods were the same as for the 500-msec delay version of Experiment 1, with the following exceptions: (1) Twenty-six participants from the same source were tested; (2) following the method used by Pratt and Fischer (2002), on every trial a cue was presented for 50 msec at fixation, centered temporally between the offset of the peripheral cue and the onset of the target (i.e., using peripheral–central cue SOAs of 50, 100, 200, and 400 msec).

Results and Discussion

The data from 2 participants who were unable to perform the memory task (they were correct on less then 25% of the trials) were excluded from all reported analyses. The overall recall accuracy, scored as for Experiment 1, was 75.3%, with a range from 95% to 46%.

The rate of responding on catch trials was 14.6% overall. Participants made more false alarms in the load condition (false alarm rate = 18.4%) than in the no-load condition (10.9%), a difference that was marginally significant [$t(23) = 1.981, p = .0596$]. The rates of anticipatory responses and misses were relatively infrequent (1% and 4.8%, respectively) and unaffected by memory load ($ps > .3$).

The RT data (upper panels of Figure 3) were subjected to an ANOVA with SOA, cue condition, and load as within-subjects variables and delay as a between-subjects factor. There were significant main effects of load [$F(1,23) = 61.08, p < .01$], cue condition [$F(1,23) = 11.56, p < .01$], and SOA [$F(3,69) = 42.9, p < .01$]. In the load condition, RTs were 56 msec slower than in the no-load condition. Overall, cued RTs were a little over 9 msec slower than uncued RTs. The main effect of SOA reflects a typical warning signal effect, with RTs decreasing as SOA increased, reaching a minimum at the 400-msec SOA and then increasing slightly. SOA interacted significantly with load [$F(3,69) = 4.73, p < .01$]; the warning signal effect was muted when there was no load. The critical interaction between SOA and cue condition was significant [$F(3,69) = 7.91, p < .01$]. No other effects or interactions were significant (Fs < 1).

To determine whether a cuing effect was present, one-tailed *t* tests were performed on cued versus uncued RTs for each combination of SOA and load. By this measure, the one nonsignificant cuing effect is marked by an ellipse in the upper panels of Figure 3. The corresponding cuing effects are shown in the lower panel. The time course of the cuing effect is highly similar in the two load conditions. In both conditions, there is net facilitation at the earliest SOA (though this is only significant in the no-load condition), and for the remaining SOAs, there is significant IOR. Importantly, and exactly as predicted by our proposal, when the return of attention was accomplished exogenously, there was no effect of memory load on the time course of the appearance of IOR.

SUMMARY AND CONCLUSION

In Experiment 1, we found that a verbal memory load delays the appearance of IOR. We attributed this effect to interference between the memory load and the endogenous return of attention to neutral after it had been captured by

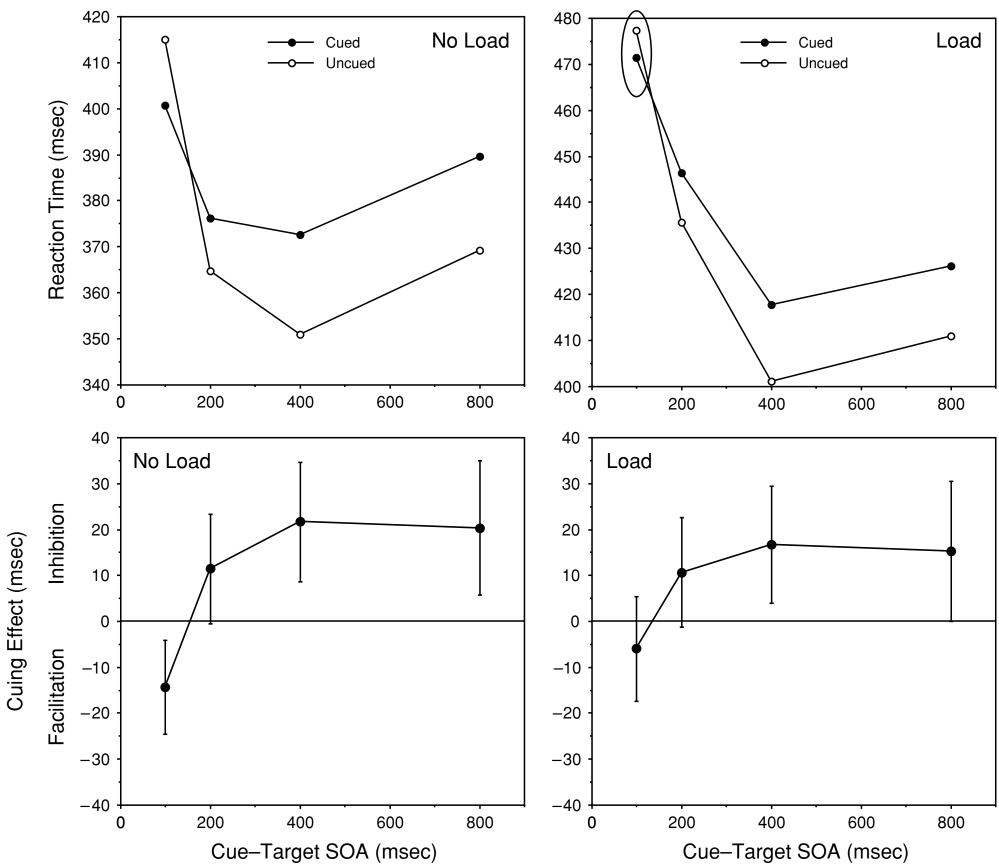

Figure 3. The reaction time results from Experiment 2 (see Figure 2 caption for explanation).

the cue. In Experiment 2, we found that the same load had no effect on the time course of IOR when attention had been returned to fixation exogenously by a second cue presented there. These findings support Klein's (2000, 2005) proposal that in the absence of an exogenous fixation cue (presented between the peripheral cue and target), the volitional disengagement of attention from a peripherally cued location and return to a neutral state, presumed to be carried out by the anterior attention system, is necessary for the relatively rapid appearance of IOR.

Whereas there is no doubt that certain subcortical structures, such as the superior colliculus (Sapir et al., 2001), are necessary for the generation of IOR, it seems that other cortically based mechanisms participate in determining properties of IOR. Evidence for this comes from the present finding that a verbal working memory load prior to a peripheral cue delays the onset of IOR's appearance, as well as a recent demonstration that a spatial working memory load presented after a peripheral cue disrupts IOR (Castel et al., 2003). These results converge with other evidence (see Klein, 2004, for a review) suggesting cortical involvement in the manifestation of IOR.

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NOTES

1. Our use of this terminology is a reflection of an unresolved question: whether IOR begins with the cue, but is overwhelmed by the facilitatory effect of attention, or whether IOR begins when attention is removed from the cued location. Studies that have accelerated the removal of attention reveal earlier IOR (e.g., Danziger & Kingstone, 1999), but this finding is ambiguous because under either view of IOR's time course this result is expected. Although there is some behavioral (e.g., Berlucchi, Chelazzi, & Tassinari, 2000) and neuroscientific (cf. Klein, 2004; Klein, Munoz, Dorris, & Taylor, 2001) evidence suggesting that IOR begins with the presentation of the cue, this is not yet firmly established.

2. As pointed out by an anonymous reviewer, "attention may have a natural propensity" to drift back toward the center of gaze. Because the normal time course of this drift may be quite slow, endogenous control or a centrally presented exogenous cue (see Experiment 2) may be needed for rapid return of attention to such a neutral state.

3. The three-way interaction of load, SOA, and cue condition was not significant [$F(3,126) = 1.429$]. As long as the diagnostic for IOR's appearance is RT(cued) > RT(uncued), this does not constitute evidence against our hypothesis. Imagine two lines that cross and a variable that shifts one line up or down by a fixed amount. The crossover point will change, but there is no three-way interaction. Even if we put this logic aside, these planned comparisons are justified by the prediction that we are testing, whether or not the omnibus *F* is significant (Keppel, 1973).

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