Inhibition of return

Raymond M. Klein

Immediately following an event at a peripheral location there is facilitation for the processing of other stimuli near that location. This is said to reflect a reflexive shift of attention towards the source of stimulation. After attention is removed from such a peripheral location, there is then delayed responding to stimuli subsequently displayed there. This inhibitory aftereffect, first described in 1984 and later labeled 'inhibition of return (IOR)', encourages orienting towards novel locations and hence might facilitate foraging and other search behaviors. Since its relatively recent discovery, IOR has been the subject of intensive investigation, from many angles and with a wide variety of approaches. After describing the seminal contribution of Posner and Cohen ('Who'), this review will discuss what causes IOR and, once initiated, what effects IOR has on subsequent processing ('What'). The time course ('When') and spatial distribution ('Where') of IOR, and what is known about IOR's neural implementation ('How') and functional significance ('Why') are also discussed.
latter situations. Inhibition of return (IOR) is such a mechanism. The initial response to a peripheral visual event is facilitation of the processing of nearby stimuli, presumably owing to a reflexive shift of attention towards the source of stimulation. However, when the event is not task-relevant and attention has had time to disengage from it, an inhibitory after-effect can be measured in delayed responding to stimuli subsequently displayed at the originally cued location. This is a prototypical example of IOR as it has been studied.

What: discovery and early characterization

It is a testament to the scientific ingenuity and rigor of its authors that so much of what we know about IOR was first demonstrated in Posner and Cohen’s seminal papers, and so many questions that have subsequently been pursued were anticipated there. In their experiments, following a peripheral cue that did not predict the location of a subsequent peripheral target (see Fig. 1a), two different procedures were used to discourage attention from remaining at the cued location: either targets were more likely to appear at fixation than at the two peripheral locations, or the fixation stimulus was flashed before target presentation.

Implicit in these manipulations is the belief that the inhibitory effect might not be seen if attention were maintained at the cued location, either because facilitation and inhibition are both initiated by the cue or because the inhibition begins when attention leaves the cued location. Reaction time (RT) was faster to targets at the cued location than to uncued targets, when the interval between the onset of the cue and onset of the target (stimulus-onset asynchrony, SOA) was short, and slower when the SOA was long. The crossover point – where facilitation changed to inhibition – was between 200–300 ms following cue onset. Nearly identical results were obtained whether the cue to do so had been central or peripheral. By interposing eye movements between the cue and the target IOR was shown to be coded in environmental rather than retinal coordinates. Although a shift of attention towards and then away from the cued location seemed strongly implicated, IOR did not follow a shift of attention that was directed endogenously (voluntarily) by an arrow presented at fixation. These are some of the key characteristics of IOR that were unveiled by its discoverers.

What: cause and effect

By naming the poorer performance at previously cued locations “inhibition of return,” Posner and Cohen’s seminal paper3, and so many questions that have subsequently been pursued were anticipated there. In their experiments, following a peripheral cue that did not predict the location of a subsequent peripheral target (see Fig. 1a), two different procedures were used to discourage attention from remaining at the cued location: either targets were more likely to appear at fixation than at the two peripheral locations, or the fixation stimulus was flashed before target presentation.

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Table 1. Conditions that elicit inhibition of return

<table>
<thead>
<tr>
<th>Condition</th>
<th>Peripheral (Exogenous)</th>
<th>Central (Endogenous)</th>
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</thead>
<tbody>
<tr>
<td>Execute saccade</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Prepare saccade</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Attend</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
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*Yes* indicates that inhibition was significant at the cued (previously fixated, prepared to fixate, attended) location.
Review

Klein – Inhibition of return

Fig. 2. Peripheral cues advance perceptual arrival times, but IOR does not delay them. Shortly after a peripheral cue, if two targets are presented simultaneously on opposite sides of fixation, with one at the previously cued location and subjects are asked to judge which one was presented first, there is a strong tendency to perceive the cued target as having been presented first. In order for the two targets to be perceived as simultaneous (subjective simultaneity, SS) when the cue–target SOA is 100 ms, the target at the cued location must be delayed by about 80 ms (shown as a positive value on the y-axis). The accelerated perception that this delay cancels is presumed to reflect the facilitative effect of attention upon stimuli at the cued location. If IOR had the opposite effect on perceptual arrival times, then at longer cue–target SOAs, when IOR operates, the effect should reverse. The target at the cued location, now retarded by IOR, will need to be presented before the uncued target in order for them to be perceived as simultaneous. This prediction of the sensory/perceptual locus of IOR is illustrated by the red portion of the diagonal line in the figure. However, the data from studies of the effect of incongruent peripheral cues on temporal order judgments do not confirm this prediction. Closed circles, data from Ref. 9; open squares, data from Ref. 10; open triangles, data from Ref. 11.

Processing. Converging evidence suggests that IOR delays both motor responses and the return of attention15. A monotonic locus was implicated in one of the earlier studies of IOR (Ref. 8). Following a peripheral cue and a return cue at fixation, two targets were presented in rapid succession, one at the cued peripheral location and one at another peripheral location. When subjects were instructed to make a saccade to whichever of the two locations seemed ‘more comfortable’, there was a significant tendency to make saccades away from the cued location. This tendency might reflect delayed perception at the cued location or a bias against making motor responses (eye movements) towards the cue. However, there was no bias when subjects were asked to make the temporal order judgment (TOJ), which of the two targets was presented first, which strongly supports a motor locus of the effect. Subsequent TOJ studies confirm this demonstration that IOR does not affect the speed with which the sensory/perceptual machinery extracts information from a previously cued location (Fig. 2; for a review, see Ref. 11, and for evidence using a different approach, see Ref. 12).

Posner et al. also demonstrated that saccades made in response to a central arrow (pointing either left or right) were delayed in the direction of a previous peripheral cue. Because, in this case, there was no peripheral event to detect, this finding provides support for a motoric basis for IOR when the response is an eye movement. Abrams and Dobkin replicated this finding16 but also reported that IOR was significantly larger when the final saccade was made in response to a peripheral event than when it was made in response to a centrally presented arrow. Although this pattern is often cited as supporting a perceptual component, there are at least two reasons to reserve judgment. The additional IOR when saccades are made to peripheral targets might merely reflect the fact that the superior colliculus, thought to be important in mediating IOR (see ‘How’ section below) is more involved in executing target-directed saccades than in executing voluntary saccades in the absence of a visual target (Ref. 11, footnote 5). Also, as noted by Taylor and Klein17, Abrams and Dobkin’s peripherally directed saccades were made in the absence of a fixation stimulus, whereas there was an arrow at fixation when saccades were elicited centrally. As IOR has been shown to be larger when the fixation stimulus is removed18, the extra inhibition with peripheral targets that Abrams and Dobkin attributed to perceptual processing could have been caused instead by fixation removal.

Although early sensory/perceptual processing may not be directly affected by IOR, indirect effects could be attributable to delayed orienting of attention towards the cued location – as in the original proposal. Klein and Taylor rejected such an ‘inhibited attention’ view, noting that IOR had been observed with simple detection, manual localization and saccadic responses, but had not been obtained when the task involved a non-spatial discrimination (of form, color or size; e.g. Ref. 16). Attention affects such discriminations, hence Klein and Taylor concluded that attention was not inhibited by IOR. They advanced instead a motor bias view... IOR is a reluctance to respond to an event at the inhibited location (in other words, IOR is more closely associated with responding than with attention)19. Subsequently, however, numerous investigators have found IOR with non-spatial discrimination tasks (e.g. Refs 17–19). How can the varied findings with discrimination tasks be explained? It appears that the timing of IOR depends on the difficulty of the target discrimination (see ‘When’ section) and that when measured at the location of a previous target rather than cue, IOR might be obscured by benefits associated with a response-repetition strategy (see Ref. 20, pp. 93–95). The likelihood of use (and magnitude of benefit) of such a strategy increases with task difficulty21. Converging evidence for the original proposal that one effect of IOR is to impede a shift of attention back to recently attended locations comes from recent studies of the effects of IOR on target detection23 (using a bias-free measure of perceptual sensitivity, d’ prime) and on early components of the brain’s electrical response to a target24.

Fuentes and colleagues have suggested that IOR is a bias against connecting perceptual representations with their usual conceptual or motor representations25. For example, when presented at a previously cued location, where inhibition would be expected to operate, irrelevant distractors and priming stimuli have an opposite effect from that expected (conflicting distractors help performance; related primes hurt performance). At first sight this effect does not appear to be straightforwardly classifiable according to the sensory/attentional/motor scheme we use here. Nevertheless, the results are quite consistent with the proposal that one effect of IOR...
is to inhibit responses that are normally associated with stimuli.

To observe IOR, investigators must satisfy two conditions: they must use a combination of methods that elicit or cause the inhibition and they must look for it using a task whose performance includes one or more stages of processing that are affected by the inhibition. While implementing this strategy it must be kept in mind that IOR is inferred from poorer performance with targets at some locations than at others. It is possible that inhibition is present but will not be seen in performance because its effects are obscured by other processes (such as facilitation or a response-repetition advantage) operating at the same time as the hypothesized inhibition. (Similarly, the facilitation that is usually present for short cue-target SOAs might be masked by procedure-dependent perceptual, decision or response processes that delay responses to valid targets26). Thus, when IOR is not obtained it could be that it was present but the task used to measure it was not sensitive to the inhibition; (2) present and measurable, but obscured by an accompanying effect in the opposite direction; or (3) not present in the first place. Discriminating amongst these alternatives is one challenge to researchers of IOR.

When: time course of IOR

IOR appears to last for several seconds, but when does it begin? In a simple luminance-detection task, Posner and Cohen varied the interval between the onset of the cue and the onset of the target to address this question (Fig. 1b). If the marker for the onset of IOR is taken as the crossover point where RT at the cued location becomes slower than RT at the uncued location, then it could be said that, from these results, IOR begins at a cue–target SOA of 235 ms (Fig. 1b). One factor underlying the onset of IOR appears to be related to the attentional demands of performing the task (to determine target identity or discriminate between targets and catch trials). Lupiáñez et al.26, for example, showed that IOR occurred later when the task was color discrimination rather than detection. IOR also begins earlier when saccadic responses are made than when manual responses are required27 (e.g. compare Fig. 1b with Fig. 3).

The concept of an attentional control setting (ACS) can be used to explain why the onset of IOR might vary with the difficulty of the task28. Let us assume that at the start of a trial the observer sets internally the level of attention that will be allocated to a target in order to perform the task: low intensity for a simple detection task, high intensity for a difficult discrimination. The peripheral cues are uninformative, and hence should not be voluntarily attended. Nevertheless, just as task switching requires time, so too does changing the attentional control setting. Therefore, the control setting selected to process the target will be in place before the onset of the cue. The higher its intensity, the more attended the peripheral cue will be because the attentional setting for the target will apply to the cue. Under the assumption that the more intensely attention is allocated to the cue the longer attention will dwell on it28, facilitation due to the allocation of attention towards the cued location will last longer the more target processing is required for successful performance (Fig. 4). A similar proposal has been made by Lupiáñez (pers. commun.).

Target discrimination difficulty is not the only variable that might affect the time course of IOR via control settings. For example, consider the presence versus absence of a distractor accompanying the target. In a block of trials where the target is never accompanied by a distractor, the target is located by its discrete onset. A control setting to find onset

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**Fig. 3.** The time course of IOR. Data from studies using a cue–saccade paradigm, with the difference (uncued minus uncued) in saccadic reaction time shown as a function of cue–target stimulus-onset asynchrony (SOA). Note that facilitation (green) at short cue–target intervals (SOAs) turns into inhibition (red) somewhere between 100 and 200 ms. ○ Ref. 18; data from four monkeys. The remaining data are from normal human observers. ● Ref. 9; ○ Ref. 27; ● Ref. 8; ▲ Ref. 61; ▽ Ref. 13; ♦ Ref. 14; ◊ Ref. 22.

**Fig. 4.** IOR onset as a function of task target difficulty. The crossover point (measured by the cue–target SOA where facilitation changes to inhibition is shown as a function of reaction time (RT) to the target [at this crossover point, when available] from three studies27,30 that manipulated the difficulty of the target task and used a range of SOAs sufficient to determine the crossover point with confidence. Circle show localization data from Ref. 27 (open circle, saccadic; filled circle, manual); squares show manual detection (open) and discrimination (filled) data from Ref. 18; triangles show manual detection (open) and discrimination (filled) data from Ref. 30.
Box 1. Hypothetical temporal dynamics of facilitation and inhibition

The data from Posner and Cohen’s seminal study (Ref. a) are plotted in Fig. 1. From performance patterns such as these, cognitive psychologists infer hypothetical inhibitory and facilitatory processes. Two different construals of the time course of these processes are illustrated.

Reference


Fig. I. Results from Posner and Cohen’s original study (Ref. a). (a) Data are plotted as a difference score (data points are cued minus uncued reaction times; RT). A negative score reflects a net facilitation at the cued location (faster RTs), whereas a positive score reflects a net inhibition (slower RTs) at the cued location. (b) One construal of the time course of two such processes, attentional facilitation (plotted in green) and inhibition of return, also acting at the cued location (plotted in red). Here, it is assumed that facilitation follows rapidly, if not immediately, after presentation of the cue and that when attention has been withdrawn from the cued location (which here takes just over 200 ms), an inhibitory process (IOR) grows in its place. Facilitation and inhibition are assumed to add linearly yielding the performance function highlighted in yellow (also in graph c). (c) A different construal of the time course of similar facilitatory and inhibitory processes. Here, it is assumed that the inhibition starts, like the facilitation, when the cue appears, and that inhibition remains constant (red), whereas the facilitation decreases over time (green). At first, there is greater facilitation than inhibition, hence the net effect on performance (black) is a faster RT at short cue–target intervals. However, net facilitation switches to net inhibition at the interval where their absolute values are equal.

This important finding does not distinguish between the view that IOR begins when attention moves away from the cued location and the view that IOR begins when the cue is presented while the early, attentionally mediated, facilitation obscures it (see Box 1).

Where: spatial distribution and coding of IOR

How is IOR distributed spatially and in what frame of reference is it coded? Posner and Cohen demonstrated that IOR is not coded in retinal coordinates but is attached to environmental locations. By interposing saccadic eye movements between the initial attention-capturing cue and the final target, the delay in responding was seen for targets appearing at the initially cued location on the screen, not on the retina. Mayer and Hocke confirmed this finding while also demonstrating a gradient in the magnitude of IOR, with inhibition declining with increasing angular distance from the originally cued location. A similar gradient for both amplitude and angle has been demonstrated in the monkey using a cue–saccade paradigm (Fig. 5).

Is inhibition of return a purely visual phenomenon, or is it represented in crossmodal spatial maps? Considering that IOR is caused by oculomotor programming and that it delays...
responses and orienting of attention towards the inhibited location, it is reasonable to expect IOR in other spatial modalities and perhaps even between modalities. Indeed this is the case: IOR has been observed in the auditory and tactile modalities and also cross-modally (for a review, see Ref. 37).

Ponsen and Cohen45 and Klein46 realized that the coding of IOR in environmental coordinates would allow it to assist visual search in static scenes by discouraging orienting (whether overt or covert) towards locations that had previously been inspected (see ‘Why’ section). In the real world, however, objects move. Suppose you enter the daycare or nursery looking for your child. As you inspect each small humanoid shape to determine if it ‘belongs to you’, some might be stationary, but some are moving. A tagging system that merely inhibited moving objects might not be sufficient in order for IOR to be observed—there must be a neural mechanism by which stimuli are inhibited or suppressed in certain spatial locations.

How: neural implementation

Converging evidence supports the view that a midbrain oculomotor structure, the superior colliculus, plays an important role in IOR. Individuals with damage to the superior colliculus (SC) show reduced or no IOR, while conversely, one hemianopic patient with visual cortex damage but an intact superior colliculus showed IOR to cues presented in his blind field45. IOR is greater for stimuli presented (monocularly) in the temporal hemifield, which has a stronger collicular representation than the nasal hemifield5 and IOR interacts with the retino-tectal pathway, the colliculus may not, itself, main-
Box 2. The foraging facilitator proposal

The rationale, method and findings from Klein’s study (Ref. a) are illustrated in Fig. 1. According to Treisman and Gelade (Ref. b) attention is required to perform a serial search task, and, by hypothesis, inhibitory tags will have been left at the location of each item after a ‘target absent’ decision. However, as attention is not required in parallel search, display locations containing items should not accrue inhibitory tags. If this functional explanation is correct, following serial search, reaction times (RT) to probes presented where there had just been a distractor (On) should exceed those to probes at previously empty locations (Off), by more than they do following parallel search. This is indeed what Klein found (Ref. a).

Three challenges to Klein’s functional explanation of IOR appeared in subsequent years. Each has recently been rebutted.

(1) When one location and then the other was cued, Pratt and Abrams (Ref. c) reported that IOR was obtained only at the most recently cued location. In visual search, if inhibition were only maintained at the most recently attended location (Off), by more than they do following parallel search. This is indeed what Klein found (Ref. a).

(2) When one location and then the other was cued, Pratt and Abrams (Ref. c) reported that IOR was observed only at the most recently cued location. (Adapted from Ref. f.)

(3) Wolfe and Pokorny (Ref. h) and later Klein and Taylor (Ref. g) reported failures to replicate the original pattern reported by Klein (Ref. a). This discrepancy has recently been resolved by Takeda and Yagi (Ref. i) and Müller and von Mühlenen (Ref. j), who showed that the original pattern depends on delivery of the probe while the search array is still present (see Fig. 1, bottom).

When the findings of Tipter et al. (Ref. f) are presented between a gap, that demonstrate that IOR is related to objects, this dependence is quite understandable: following a scene change signalling a new search environment it would not be functional for IOR to be maintained.

References

- Snyder, J.J. and Kingstone, A. Inhibition of return and visual search: how many intervening cues change IOR? Hum. Percept. Perform. 24, 1467–1475

Fig. 1. Functional explanation of IOR. Klein hypothesized that, in parallel search, the difference between reaction times (RTs) to probe targets presented at distractor locations (On) and empty locations (Off) should be less than in serial search, as in the latter, inhibitory ‘tags’ will be left at each location attended to. This hypothesis was borne out by the experimental data (RT differences are given as On minus Off), and it was shown later, by two other groups, that this effect may still be observed when up to four intervening cues are presented between a gap and a subsequent target at the same location. (Adapted from Ref. f.)

Fig. 2. IOR with Intervening cues. Data showing that significant IOR is still observed when up to four intervening cues are presented between probe and a subsequent target at the same location. (Adapted from Ref. f.)
the search array was removed when the probe was presented, confirming other recent studies showing that IOR following visual search depends upon maintenance of the search array. Pre-probe saccades showed a strong directional bias away from a previously fixated region, probably reflecting IOR. Together with recent studies that replicate the finding of inhibition at distractor locations following saccades but not parallel visual search — so long as the search array remains visible — these data strongly support the proposal that IOR functions to facilitate visual search by inhibiting orienting to previously examined locations.

What’s in a name?

As presented here, IOR is generated within a system that is normally responsible for orienting of gaze direction. IOR inhibits orienting of covert attention, of gaze direction, and, more generally, of spatial responses towards tagged locations and objects. By biasing orienting away from already inspected items IOR functions to make search of the environment more efficient. The presentation in this review of IOR, from its discovery by Posner and Cohen in 1984 to the present day, is perhaps more integrated than might be inferred from an exhaustive survey of studies that lay claim to the term. Some investigators have observed inhibitory effects for non-spatial attributes of irrelevant pre-cues (e.g. repeating colors at fixation), repeating a particular pitch at any location, which they assume exemplify IOR. Similarly, Houghton and Tipper’s 

computational model of negative priming (presumably an inhibition of the features of irrelevant distractors) can also generate IOR from irrelevant cues. In contrast to these possible over-extensions of the term Watson and Humphreys have demonstrated a marking process during visual search that appears to function like IOR, but they believe, perhaps too restrictively, that visual marking is distinct from IOR. As our knowledge of the characteristics of IOR and its neural implementation grows, there will hopefully be increasing agreement on the use of the term. In the meantime, it is important to be careful but open-minded when choosing terms to divide up the psychological–biological realm.

**Outstanding questions**

- Is the removal of attention from a ‘cued’ location the signal for IOR to begin there, or is IOR time-locked to the appearance of the cue?
- To establish firmly that IOR delays attention, it would be useful to measure the time course of attentional shifts (under exogenous and endogenous control) towards previously cued versus uncued locations.
- If parietal cortex and the superior colliculus jointly implement IOR, how is this achieved?
- Once caused, does IOR have separable effects on oculomotor and attentional responses? For example, would the inhibition observed by Klein and MacInnes in their camouflaged search task generalize to non-oculomotor responses?
- What is the relationship between IOR and other effects with a surface similarity (visual marking, repetition blindness, attentional momentum, negative priming, foveal IOR)? How might these different effects be implemented in the brain?

**Box 3. IOR of eye movements during search**

The observer fixes a small black disk at the center of an empty screen when the image to be searched (a picture from the Where’s Waldo™ series of books) is presented. After several saccades were made (illustrated with blue arrows in Fig. Ia) as the observer searched for Waldo or another item, the fixation stimulus reappeared unexpectedly at carefully selected locations (indicated by black circles) while the search array remained (Fig. Ib) or was removed (Fig. Ic). The task was to fixate the target as rapidly as possible. Arrows illustrate a saccade to the target in the 0 deg. condition. In one experiment this target was presented at the most recently fixated location or other locations around an equi-eccentric circle (line back). Shown in Fig. Id are the data from the experiment where the paradigms fixation (labeled 0 here) was used to generate target locations (two back). Saccadic reaction time when the target was located by the first post-target saccade (as in a) increased with increases in the target’s proximity to a previously fixated region, but only when the scene was maintained.

Reference


In order to study whether unattended stimuli can capture attention, researchers must first operationally define a way to measure the capture of attention. Two classes of definitions have been used in the study of attentional capture. ‘Explicit attentional capture’ occurs when a salient and unattended stimulus draws attention, leading to awareness of its presence. ‘Implicit attentional capture’ is revealed when a salient and irrelevant stimulus affects performance on another task, regardless of whether or not subjects are aware of the stimulus. The first, explicit attentional capture, is perhaps the more intuitive conception: when someone across a room says our name or waves at us vigorously, the stimulus signal segregates itself from the background and we become aware of its source. Typically, studies adopting the explicit approach determine whether capture has occurred by asking subjects whether they noticed the critical stimulus. Although reporting the presence of an unexpected object may not conclusively demonstrate attentional capture, the failure to notice it suggests that the object failed to capture attention explicitly. Several recent studies of explicit attentional capture have found that when observers are focused on some other object or event, they often fail to notice salient and distinctive objects, a phenomenon that is termed ‘inattentional blindness’. Although the use of explicit reports was one of the first approaches used to study attentional capture (in the study of divided and selective attention), and despite a recent resurgence of interest in inattentional blindness, most recent studies have focused on implicit attentional capture. That is, such studies make the critical stimulus irrelevant to the primary task and infer capture based on different patterns of response times or eye movements. This review considers evidence for attentional capture in both implicit and explicit paradigms. Together, these findings raise the intriguing possibility that salient stimuli, including the appearance of new objects, might not always capture attention in the real world.

Implicit measures of attentional capture
Most recent studies of attentional capture have adopted methodologies used extensively in the study of visual search. Four distinct paradigms have been used to explore implicit attentional capture and inattentional blindness

Daniel J. Simons

Although we intuitively believe that salient or distinctive objects will capture our attention, surprisingly often they do not. For example, drivers may fail to notice another car when trying to turn or a person may fail to see a friend in a cinema when looking for an empty seat, even if the friend is waving. The study of attentional capture has focused primarily on measuring the effect of an irrelevant stimulus on task performance. In essence, these studies explore how well observers can ignore something they expect but know to be irrelevant. By contrast, the real-world examples above raise a different question: how likely are subjects to notice something salient and potentially relevant that they do not expect? Recently, several new paradigms exploring this question have found that, quite often, unexpected objects fail to capture attention, a phenomenon known as ‘inattentional blindness’. This review considers evidence for the effects of irrelevant features both on performance (‘implicit attentional capture’) and on awareness (‘explicit attentional capture’). Taken together, traditional studies of implicit attentional capture and recent studies of inattentional blindness provide a more complete understanding of the varieties of attentional capture, both in the laboratory and in the real world.

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Klein – Inhibition of return


59

59

60

60

61
