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Michael D. Dodd · Jay Pratt

Rapid onset and long-term inhibition of return in the multiple cuing paradigm

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Abstract Inhibition of return (IOR) refers to the finding that targets at cued locations are responded to more slowly than targets at uncued locations when a relatively long temporal interval occurs between the two events. In studies which have examined the time course of IOR (e.g., Samuel & Kat in *Psychonomic Bulletin & Review*, *10*, 897–906, 2003), the effect is generally shown to develop at around 200 ms and dissipate at around 3,000 ms following a cue. A number of recent studies, however, have demonstrated that IOR can develop much more quickly (up to 50 ms following a cue) and last much longer (up to 13 min following a cue) in certain tasks. The present study uses the multiple cuing paradigm to determine whether IOR can be observed outside the normally reported temporal boundaries (300–3,000 ms) when attention is shifted very quickly (every 15 ms) or very slowly (every 1,500 ms) throughout the visual field. IOR was observed as quickly as 30 ms following cue onset and as long as 6,000 ms following cue onset. Implications for the role of IOR in visual search are discussed.

Introduction

We are continually confronted with far more visual input than can be processed simultaneously. Consequently, a critical function of our visual system is to efficiently direct attention to features of our environment to determine which stimuli are to be processed and which are to be ignored. One process that is thought to facilitate the acquisition of new visual information is inhibition of return (IOR). IOR refers to the finding that targets that appear at previously attended or cued locations are more slowly responded to than targets that appear at uncued locations when a relatively long temporal interval (typically between 300 and 3,000 ms; Samuel & Kat, 2003) intervenes between the two peripheral events (e.g., Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985; for a review, see Klein, 2000). Since its initial discovery, it has been repeatedly suggested that IOR is a process which facilitates visual search by continuously biasing attention to novel locations in the visual field (e.g., Klein, 1988; Pratt, Kingstone, & Khoe, 1997; Tipper, Weaver, Jerreat, & Burak, 1994). Evidence supporting a role for IOR in visual search, however, has not been overwhelming, with some researchers providing evidence for a strong role of the effect in visual search (e.g., Klein, 1988; Klein & MacInnes, 1999), others providing evidence for a limited role of the effect in visual search (e.g., Gilchrist & Harvey, 2000), and still others providing evidence that IOR plays no role in visual search (e.g., Horowitz & Wolfe, 1998, 2001, 2003). This inconsistency is likely attributable to the fact that there is no agreed upon measure of IOR in visual search. For example, it is unclear whether eye movements should be allowed and whether IOR should be measured as a function of the time it takes to respond to an onset stimulus or as a function of eye movements and refixations. The absence of a prevailing method of measuring IOR in search situations makes it difficult to compare experiments and to test predictions in this area.

If IOR is going to have a real impact on search efficiency, it would have to emerge rapidly and coexist at multiple locations, given that we typically attend quickly to a number of different areas in our environment (e.g., when we look for a friend in a crowd or our car in a parking lot). Moreover, some form of memory must drive the effect so as to keep track of where attention has been and to ensure that it does not return there.

M. D. Dodd (✉)
Department of Psychology, University of British Columbia,
2136 West Mall, Vancouver, BC, Canada V6T 1Z4
E-mail: mike@psych.ubc.ca
Tel.: +1-604-8220069
Fax: +1-604-8220069

J. Pratt
University of Toronto, Toronto, Canada

Unfortunately, however, the majority of IOR experiments involve only a single, and relatively slow, shift of attention and, therefore, the paradigms with which the effect is being investigated do not generalize well to visual search. To address these limitations, a number of researchers have examined IOR within the context of search-like tasks and have provided evidence that IOR may play a role in visual search. For example, Tipper, Weaver, and Watson (1996) were the first to demonstrate that IOR can accrue to multiple locations simultaneously when multiple placeholders (in this case, four placeholders arranged around fixation in a plus sign pattern) are used. On each trial, three locations were sequentially cued followed by the presentation of a target requiring a detection response. IOR was observed at all three cued locations and the magnitude of IOR was greater for the more recently cued locations (i.e., cues that appeared closer in time to the target) than for earlier cued locations, a pattern of results that would soon become the signature of this paradigm.

Similarly, Danziger, Kingstone, and Snyder (1998) used a visual display consisting of five peripheral placeholders equally spaced around a central fixation point. On each trial, up to three of the placeholders were cued sequentially for a duration of 100 ms. To reduce certainty as to when the target would appear, participants did not know how many locations would be cued on a given trial. IOR was observed at every cued position, and this was true with either a detection response or a discrimination response. As in Tipper et al. (1996), the magnitude of IOR was greater for the more recently cued locations relative to the earlier cued locations.

To further determine the number of locations that could be simultaneously inhibited, Snyder and Kingstone (2000, 2001) expanded the Danziger et al. (1998) paradigm by increasing the number of possible target locations to eight and the number of cues to six (with a duration of 500 ms for each cue). IOR was observed at the five most recently cued locations, and the magnitude of IOR decreased as a function of when the cue occurred, with greater IOR effects observed at more recently cued locations relative to earlier cued locations. Dodd, Castel, and Pratt (2003) extended this line of research to determine whether IOR could accrue to multiple locations with rapid shifts of attention. To this end, five of six possible locations were cued sequentially on each trial, but with stimulus onset asynchronies (SOAs) similar to that of the previous studies (500 ms) or much shorter (50 ms). The typical decline of IOR across the five cued locations was found in the 500 ms SOA condition. Although fewer locations showed IOR in the 50 ms SOA condition, the fact that IOR was found at all indicates that inhibitory tags can be encoded and maintained in a very rapid manner.

The aforementioned results are consistent with a role for IOR in visual search as they provide evidence that IOR can develop rapidly and accrue to multiple locations simultaneously. Two issues, however, remain unresolved. The first relates to exactly how quickly IOR can develop in a search-like situation. Though Dodd et al. (2003) observed IOR with 50 ms shifts of attention, the earliest cue–target SOA at which IOR occurred was 100 ms (IOR was observed at the second to last cued location in their Experiment 1). In non-search situations, both Danziger and Kingstone (1999) and Spalek (submitted) have demonstrated that IOR can accrue to a single cued location as quickly as 50 ms following a cue when either (a) the cue predicts that the target will appear at another location or (b) attention is rapidly removed from the cued location via a fixation cue. The aforementioned results suggest that IOR can develop much sooner than 300 ms (e.g., 50 ms) following a cue so long as attention is rapidly disengaged from the cued location. It has been proposed, however, that objects/locations may be searched as quickly as one item every 13–44 ms (Wolfe, Alvarez, & Horowitz, 2000), suggesting that IOR would need to develop extremely rapidly to play a role in search behavior. Thus, in the present experiment, we use cue durations of 15 ms (technological limitations prevent us from presenting cues faster than 15 ms) to determine how quickly IOR can develop in a search-like task. Given the aforementioned results, we expect to observe IOR with 15 ms duration cues, but it is unclear exactly how quickly IOR will develop.

The second issue relates to the duration of IOR in search-like tasks. For IOR to influence search efficiency, it would be useful if the effect were long lasting for situations in which the search is long and complex (e.g., looking for your car in a crowded parking lot). In studies which have examined the time course of IOR, however, the effect dissipates around 3,000 ms following a cue (e.g., Castel, Chasteen, Scialfa, & Pratt, 2003; Samuel & Kat, 2003). It is important to note, however, that these examinations of time course have relied on the Posner and Cohen (1984) paradigm for measuring IOR, which involves a single, relatively slow shift of attention. In a typical visual search, multiple rapid shifts of attention are made and there is reason to believe that continuous shifts of attention may influence the time course of IOR. Recently, Dodd, Castel, and Pratt (submitted) have provided evidence that the magnitude of IOR increases with subsequent shifts of attention, which suggests that the influence of IOR on a search task may increase over time. By holding the time constant and manipulating the number of cues appearing prior to target onset, Dodd et al. were able to compare the magnitude of IOR at a cued location preceding/following 0, 1, or 2 additional cues and observed greater magnitude IOR as the number of preceding cues on a trial increased. Consequently, these researchers concluded that the oft observed pattern of results in the multiple cuing paradigm (with the largest magnitude of IOR being observed at the most recently cued location and the smallest magnitude of IOR being observed at the earliest cued location), which has been described as a 'decline' in the magnitude of IOR across cues, is actually an increase in the effect with each subsequent shift of attention. On the basis of these, and other, results, Dodd et al. suggested that the influence of IOR on search may increase as task difficulty increases, meaning that the magnitude and time course of IOR in a difficult search situation may extend beyond that typically observed following only a single shift of attention. Thus, in the present experiment, we examine whether multiple shifts of attention also influence the time course of IOR by presenting cues of a very long duration (1,500 ms per cue). This timing ensures that the entire cuing sequence extends well beyond the normally reported boundaries of IOR (3,000 ms, Samuel & Kat, 2003) and that attention should continually move throughout the cuing sequence, albeit slowly. If continual shifts of attention influence the time course of IOR, we would expect to observe the effect well outside of the temporal boundary that has been observed in single cue studies (3,000 ms).

The present study was conducted to determine (a) how quickly IOR can develop in a multiple cuing task and (b) whether IOR can extend beyond the normally reported temporal boundaries when attention is continually shifted prior to target onset. To address these questions, we used a modified version of the multiple cuing paradigm employed by Dodd et al. (2003) (see also Danziger et al., 1998; Snyder & Kingstone, 2000, 2001)—in which five of six locations are sequentially cued prior to target onset—but used cues of either a 15 or 1,500 ms duration. Thus, the SOA from the onset of the first cue to the onset of the target was only 75 ms in the fast cue condition and 7,500 ms in the slow cue condition. Given that IOR usually begins around 300 ms and dissipates around 3,000 ms when single cues are used, one might expect that IOR should not be observed in the present experiment as the cuing sequence is well outside the temporal boundaries of where IOR is typically found. In single cue studies, however, there is neither an immediate need to disengage attention from a cued location nor a reason to continuously shift attention prior to target onset, two factors that we argue are critical to the development of IOR in search-like situations. Thus, we predict that IOR will be observed in both cue conditions. Of critical interest, however, is how quickly IOR develops and how long IOR lasts, following cue onset.

Method

Participants

Eighteen undergraduate students from the University of Toronto volunteered to participate in the experiment and received course credit for their participation. All participants had normal or corrected-to-normal vision and were naïve about the purpose of the experiment, which took place in a single 1 h session.

Apparatus and procedure

The experiment was conducted using a Pentium computer with a VGA monitor in a dimly lit, sound attenuated testing room. Participants were seated 44 cm from the front of the computer monitor with their heads held steady by a chin and headrest. A keyboard was placed directly in front of the participant and they made responses using the space bar on the keyboard.

There were two blocks of trials (one testing IOR following the presentation of very fast cues and the other following the presentation of very slow cues) and each participant completed each block. Block order was counterbalanced across participants. At the beginning of each trial, a central fixation point (white, 0.2° in diameter) and six white outline square placeholders (each subtending 1° and displayed in a circular arrangement around fixation) were presented on the computer monitor with a black background (see Fig. 1).

Participants were instructed to fixate on the central fixation point, and not to make any eye movements. Following a period of 1,000 ms, one of two cuing sequences was initiated as a function of block type. In the fast cue condition, five of the six squares were cued sequentially by placing a white circle (subtending 0.8°) inside the placeholder for a period of 15 ms. The onset of each subsequent cue began immediately after the offset of the cue that had preceded it. The cue locations were randomized on each trial, with the limitation that a location could be cued only once per trial.[1] The participants were explicitly informed that the cues were not predictive of the location of the upcoming target. Following the offset of the fifth cue, a target (a green square that filled the entire placeholder) appeared immediately inside one of the six placeholders on the screen. The target was equally likely to appear inside any of the six placeholders and remained on the screen until a response was registered. The slow cue procedure was identical to the fast cue procedure, except that the duration of each cue (including the fixation cue) was 1,500 ms.

Participants were instructed to press the spacebar as soon as they detected the target and were told to respond as quickly and accurately as possible. To reduce anticipatory responses, catch trials in which the target

[1] It is worth noting that one flaw that is inherent in practically all experiments using the multiple cuing paradigm is that the requirement to only cue a location once on each trial leads to the possibility that participants will develop unwanted contingencies regarding the cues (e.g., having seen four cues, participants know there is a 50% chance that a cue will appear in one of the two remaining locations on screen whereas prior to the presentation of any cues, there is a 16.67% chance that a cue will appear in one of the six remaining locations on the screen). It is difficult to determine whether these contingencies also influence reaction times and this is an important issue for future study. It is worth noting, however, that in the prior experiment one might expect such contingencies to come into play more so with 1,500 ms cues relative to 15 ms cues (assuming these contingencies take some time to develop) but there is little difference in the magnitude of IOR between these conditions (as would be expected, however, reaction times are faster with 15 ms cues relative to 1,500 ms cues).

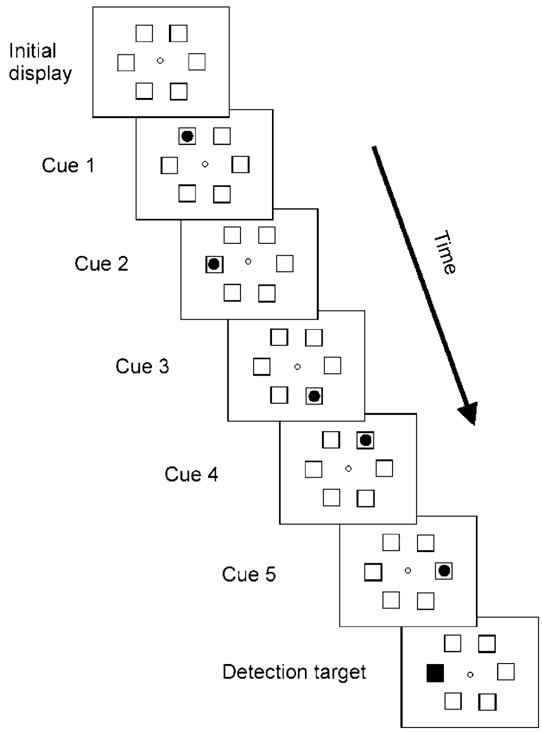

Fig. 1 Trial sequence used in the present study. The initial display was on for 500 ms, and the five cues were presented for either 1,500 ms each or 15 ms each

did not appear were also included and participants were told not to respond if the target did not appear. Incorrect responses on catch trials (and responses less than 100 ms and greater than 1,000 ms) were considered errors, and a short error tone was presented if any of these occurred. In addition, participants were instructed to remain fixated on the central fixation point, and their gaze was monitored with a closed circuit camera system to ensure that eye movements were not being made. The next trial began 1,000 ms after each response.

Design

The experiment consisted of two blocks of 200 trials, with 150 test trials and 50 catch trials in each block. Short breaks were given after every 100 trials.

Results and discussion

Errors occurred on less than 1.4% of all trials. Incorrect responses on catch trials occurred on 2.2% of all catch trials (0.55% of all trials); responses less than 100 ms occurred on 0.9% of all test trials (0.68% of all trials); and responses greater than 1,000 ms occurred on 0.2% of all test trials (0.15% of all trials). These trials were excluded from all subsequent analyses. Reaction times for targets appearing at each location as a function of cue condition, as well as the IOR effects for each cue condition, are presented in Table 1. The magnitude of IOR at each location for each condition is also shown graphically in Fig. 2. The RTs for targets appearing at each individual cued position were collapsed across trials, as were the RTs for targets appearing at an uncued position.

To examine the IOR by position effects, the mean RTs were analyzed with a 2 (cue condition: fast vs. slow) × 6 (target position) ANOVA. There was a significant main effect of cue condition, $F(1, 17) = 18.62$, MSE = 2,796.57, $P < 0.001$, with faster RTs for targets in the short cue condition relative to targets in the long cue condition. In addition, there was a significant main effect of target position, $F(5, 85) = 4.31$, MSE = 272.34, $P < 0.002$, with generally longer RTs observed for targets appearing in recently cued locations relative to targets appearing in earlier cued locations or the uncued location and a significant interaction between cue condition and target position, $F(5, 85) = 2.99$, MSE = 260.39, $P < 0.02$.

The total amount of IOR as a function of cue position can be seen graphically in Fig. 2. In the fast cue condition, significant IOR was observed at four of the cued locations by comparing the RTs for targets appearing at each cued location to the RTs for targets appearing at the uncued location (for *t* tests, all *P*s < 0.05). Interestingly, the only cued location that did not elicit significant IOR was the most recently cued location, which is normally the location where the largest amount of IOR is observed with this type of paradigm. Given that the onset of the last cue precedes the target by only 15 ms, however, it is reasonable to posit that there was simply not enough time for that location to be inhibited, or that there was some form of facilitation offsetting inhibition at this location. Dodd et al. (2003) also failed to observe IOR at the most recently cued location with 50 ms cues, so the present result is not surprising. That IOR was observed at the second to last cue location though is evidence that a location can be inhibited as early as 30 ms following cue onset.

In the slow cue condition, significant IOR was also observed at four of the cued locations (every position except cue 1; all *P*s < 0.05). That IOR was observed at the second cued location is evidence that inhibitory tags can be maintained for as long as 6,000 ms following cue onset. It is worth mentioning that the expected pattern of IOR with multiple cues (with the most IOR at the most recently cued location and the least at the earliest cued location) was observed in the slow cue condition of the present experiment, but not in the fast cue condition. It may be that this pattern of IOR is dependent on the speed with which attention moves and in the present experiment, attention was moving much more rapidly or much more slowly than would normally be the case. Moreover, the size of the inhibitory effect at all locations (except cue 5 in the long cue condition) is smaller in magnitude than the IOR that is elicited following more standard cue–target SOAs (though the magnitude of IOR is commensurate with the results of Dodd et al.,

Table 1 Mean RTs (in ms), standard deviations (in brackets next to each RT), and IOR effects (cued–uncued, in ms) for targets appearing at each possible location for the two conditions

Cue condition		Cue type					
		Cue 1, 5-back	Cue 2, 4-back	Cue 3, 3-back	Cue 4, 2-back	Cue 5, 1-back	Uncued
Fast cues (15 ms)	Mean RT	323 (23)	321 (42)	326 (41)	321 (46)	319 (44)	313 (51)
	IOR effect	10	8	13	8	6	
Slow cues (1,500 ms)	Mean RT	345 (54)	355 (70)	353 (58)	352 (65)	369 (62)	341 (54)
	IOR effect	4	14	12	11	28	

2003, who used the identical paradigm with 50 ms duration cues), which may also suggest that the magnitude of IOR is influenced by the speed with which attention is moving throughout the visual field. In any case, the important finding in this experiment is that IOR was observed outside of the normally reported temporal boundaries. Previously, it had been well established that IOR developed around 300 ms following the onset of a cue and dissipated after 2,000–3,000 ms. The present results, however, provide evidence that IOR can develop much sooner (as early as 30 ms from the target)—and dissipate much later (as late as 6,000 ms following a cue)—than had been previously thought, so long as the individual is continuously shifting their attention throughout the experimental display.

General discussion

The goal of the present study was to determine how quickly IOR can develop, and how long IOR can last, in search-like tasks using the multiple cuing paradigm. In each of the present cue conditions, IOR was observed at four of the five cued locations, with only the first cued location not eliciting IOR in the slow cue condition and only the last cued location not eliciting IOR in the fast cue condition. Thus, IOR developed as quickly as 30 ms following cue onset and lasted up to 6,000 ms following

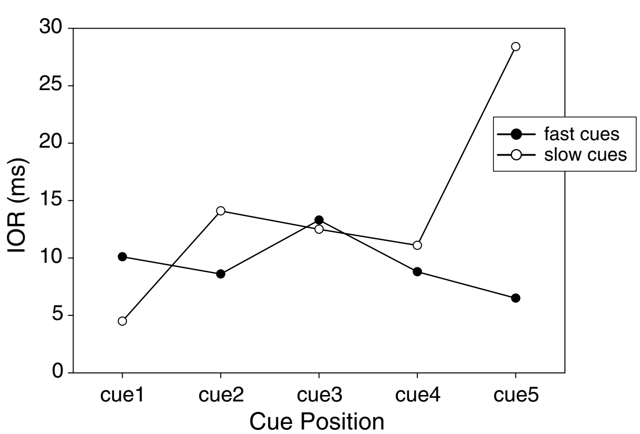

Fig. 2 Amount of IOR (ms) as a function of each cued position (calculated by subtracting the mean RT of each cued position from the mean RT of the uncued position) for the two cue conditions

cue onset, well outside of the generally reported boundaries of the effect (300–3,000 ms). Thus, the present results are consistent with Danziger and Kingstone (1999), Dodd et al. (2003), and Spalek (submitted), all of whom reported IOR as early as 50 ms following a cue so long as attention was rapidly disengaged from the cued location. It is worth noting, however, that our finding of IOR 30 ms following cue onset is the fastest that IOR has ever been shown to accrue to a previously attended location in a search-like task. Interestingly, while many researchers have often thought of IOR as not developing until the initial facilitation at a cued location dissipates, an alternative view that has been put forth is that inhibition is initially generated when a cue onsets, but that this inhibition is initially overpowered by a strong facilitatory effect that decreases rapidly over time, giving way to IOR (Klein, 2000). Under this view, IOR would normally emerge around 300 ms following a cue—given that it take approximately 200 ms for facilitation to dissipate—but could emerge earlier if something occurs to reduce/eliminate the strong facilitatory effect. In the present study, the rapid onset of additional cues should lead to the disengagement of attention from the cued location which in turn would reduce facilitation and allow IOR to manifest itself earlier than it would otherwise at each cued location. Thus, the present results are consistent with the possibility that inhibition begins initially with the presentation of the cue.

The present study also adds to a growing literature which demonstrates that IOR can endure longer than suggested by studies that have used single cue paradigms. IOR has generally been shown to dissipate after about 3,000 ms, but we observed IOR 6,000 ms after cue onset when attention was continuously shifted between cue onset and target onset. Similarly, Wilson, Castel, and Pratt (submitted) observed IOR up to 10 s following an initial cue in a go/no-go task that employed more standard targets. Moreover, Tipper, Grison, and Kessler (2003) reported IOR at intervals ranging from 3 to 13 min for face stimuli. Tipper et al. attributed this finding to the encoding of the face stimuli into memory "along with associated inhibitory states" (p. 22). While previous demonstrations of long-term IOR are often posited to be attributable to different underlying mechanisms than IOR observed in the Posner and Cohen (1984) paradigm, it is important to note that both of these long-term IOR experiments required continual (and multiple) peripheral shifts of attention to other stimuli between the cue and target trials. Thus, it could be that IOR is intended to facilitate the visual system in the presence of multiple stimuli, a situation that cannot be adequately addressed by the majority of single cue studies. With multiple cues we create a situation where the visual system needs to attend to a number of locations in a short period of time, which is perhaps more similar to our real world experience, wherein the visual system is constantly bombarded by multiple stimuli. While we are not sure how long IOR can last, the present results, in accordance with those of Tipper et al. (2003) and Wilson et al. (submitted), provide solid preliminary evidence that IOR can exist well beyond 3 s, and that this longer term IOR effect appears to be dependent on continuous shifts of attention (Dodd et al., submitted).

The finding that IOR can accrue to a location as quickly as 30 ms following cue onset and last up to 6,000 ms following cue onset has important ramifications for the role of IOR in visual search. There is currently a debate in the literature as to whether IOR can influence search behavior. For example, Horowitz and Wolfe (1998, 2001, 2003) have repeatedly reported findings consistent with the notion that visual search is memory-free and, as such, have suggested that IOR should not influence tasks requiring rapid deployments of attention (e.g., < 100 ms). Dodd et al. (2003), however, disputed this claim by demonstrating that locations can be inhibited with cue durations of only 50 ms. Moreover, both Gilchrist and Havery (2000) and Klein (1988) (see also Klein & MacInnes, 1999) have provided evidence that IOR can influence both oculomotor behavior and target detection in actual search tasks. The present results are more consistent with the findings of Gilchrist and Harvey and Klein and colleagues than the findings of Horowitz and Wolfe. Though the present experiment was not designed to explicitly test whether IOR can influence search behavior, the data satisfy the earlier outlined criterion that IOR needs to meet if it is going to impact search: IOR can emerge rapidly and coexist at multiple locations for fairly long periods of time (up to 6,000 ms). Moreover, Klein (2004) has reviewed neuroscientific evidence that is consistent with the notion that IOR begins with the presentation of the cue (a possibility which is consistent with the present data) and, consequently, has argued that it is highly likely that IOR can develop quickly enough to influence search behavior. Collectively, these studies provide strong evidence implicating a role for IOR in visual search.

Though we observed IOR as quickly as 30 ms following a cue and as long as 6,000 ms following a cue, it is important to note that the onset and duration of IOR are likely affected by a variety of factors, such as the speed with which attention moves throughout the visual field. It is unlikely, therefore, that IOR would be observed 6,000 ms following a cue if attention were continually moving at a rate of one location/object every 15 ms. For this to occur, hundreds of locations would need to be inhibited and held in spatial working memory simultaneously (Castel, Pratt, & Craik, 2003). Though it is currently unclear how many locations can be simultaneously inhibited (e.g., Takeda, 2004, has suggested that up to 20 locations can be inhibited simultaneously while Snyder & Kingstone, 2000, 2001, have argued that only five locations can be simultaneously inhibited), there is likely a limit on the number of locations/objects that can be held in spatial working memory. Similarly, IOR would never develop as quickly as 30 ms following cue onset in situations where attention is moving slowly throughout the visual field. Further research is required, therefore, to determine the influence of the speed of attention shifts on the magnitude and duration of IOR.

In summary, the present research demonstrates that IOR can be observed well outside of the normally reported temporal boundaries (between 300 and 3,000 ms) that were originally reported by Posner and Cohen (1984) so long as attention is rapidly disengaged from an attended location and continually shifted to new locations. Moreover, the present results add to a growing literature which suggests that both the formation and magnitude of IOR are influenced by continuous shifts of attention. This has important implications for the role of IOR in visual search, as well as memory-based accounts of IOR. Collectively, these findings shed considerable light on IOR as it appears to be faster acting, longer lasting, and more pervasive than originally thought.

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