

# Fruitful visual search: Inhibition of return in a virtual foraging task

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Inhibition of return (IOR) has long been viewed as a foraging facilitator in visual search. We investigated the contribution of IOR in a task that approximates natural foraging more closely than typical visual search tasks. Participants in a fully immersive virtual reality environment manually searched an array of leaves for a hidden piece of fruit, using a wand to select and examine each leaf location. Search was slower than in typical IOR paradigms, taking seconds instead of a few hundred milliseconds. Participants also made a speeded response when they detected a flashing leaf that either was or was not in a previously searched location. Responses were slower when the flashing leaf was in a previously searched location than when it was in an unvisited location. These results generalize IOR to an approximation of a naturalistic visual search setting and support the hypothesis that IOR can facilitate foraging. The experiment also constitutes the first use of a fully immersive virtual reality display in the study of IOR.

When attention is focused on a location, stimuli at that location are detected more readily. For example, when their attention is summoned to a location by a flashed cue, people are faster to detect stimuli presented near this cue. However, when the delay between the flashed cue and the subsequent appearance of the stimulus is long enough, people are actually slower to detect the stimulus at the cued location than at other locations in the display. Presumably, after a delay, attention is no longer focused on the cued location, and that location thus receives no processing benefit. Moreover, processing at that location might even be inhibited, making people less likely to refocus attention on that location (Posner & Cohen, 1984). Such an inhibitory mechanism, now known as inhibition of return (IOR; Posner, Rafal, Choate, & Vaughan, 1985), could bias processing in favor of sampling of new information in the visual field.

IOR is most practically relevant in the context of visual search performance. Search is more efficient if participants attend to new items rather than repeatedly searching previously examined ones, and IOR encourages orienting toward new items and away from searched items (Klein, 1988; Klein & MacInnes, 1999; MacInnes & Klein, 2003; Müller & von Mühlenen, 2000; Takeda & Yagi, 2000).

When participants must detect a probe during a difficult visual search task, they detect probes in empty locations faster than those in locations occupied by visual search items. However, this effect occurs only if the probe appears while the search array is still present, suggesting that this visual search IOR is object based (see Klein & Taylor, 1994, and Wolfe & Pokorny, 1990, for failures to replicate Klein, 1988, that are resolved with this explanation). The presence of IOR in simple, computer-based visual search tasks is imbued with practical significance; it might serve to facilitate foraging (see, e.g., Klein, 2000; Klein & MacInnes, 1999; Tipper, Weaver, Jerreat, & Burak, 1994).

In one test of the foraging facilitator hypothesis (Klein & MacInnes, 1999), participants searched for a character in the cluttered drawings of a *Where's Waldo?* book while experimenters monitored their eye movements. In addition to searching for their target, participants had to make a saccade to a flashed probe whenever it appeared. When the probe appeared in a previously fixated location, saccadic latencies were longer than when the probe appeared at other locations. Furthermore, saccades made prior to probe onset were typically biased away from previous saccadic directions, providing further support for the notion that IOR directs attention to new locations during visual search. IOR and the saccadic direction bias occur even when the probe appears after participants have stopped their visual search and are inspecting a target of their choice (MacInnes & Klein, 2003). In this case, IOR occurs in the absence of a programmed eye movement, suggesting that IOR results from attentional biases rather than biases in oculomotor programming (but see Hooge, Over, van Wezel, & Frens, 2005).

Most experiments assessing whether IOR acts as a foraging facilitator have employed simple, computer-based

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search tasks, often using saccades as the primary dependent measure. However, for IOR to have practical significance as a foraging facilitator, it should operate in other contexts as well—does it operate in more complex search tasks that more closely approximate real-world foraging than the usual visual search task? If IOR is a foraging facilitator, its effect might be amplified by tasks that more closely approximate natural foraging. One recent study examined whether visual search is an adequate model of foraging behavior in general (Gilchrist, North, & Hood, 2001). In this study, participants searched film canisters arranged on the floor for the one containing a marble, walking around and bending down to shake each canister to determine if it was the target. As in visual search tasks, search time increased linearly with set size, with a target-present to target-absent search slope ratio of approximately 1:2. Unlike in a traditional visual search, however, participants rarely revisited previously searched items, suggesting an increased role for memory that is consistent with IOR. Although IOR was not systematically examined in this study, the results are consistent with the idea that IOR applies in a more realistic foraging context. No studies have systematically examined whether IOR occurs in the context of manual foraging and, if so, whether the IOR effect would be larger in approximations of natural contexts.

Here we investigate the efficacy of the foraging hypothesis in a task that is closer to natural foraging than the usual visual search task. Whereas previous IOR studies conducted visual search tasks using small 2-D computer displays and measured IOR as a function of saccadic reaction times (RTs), we examined IOR by having partici-

pants conduct a manual search of a 3-D, room-size virtual display. Participants searched for fruit on a tree in a fully immersive virtual environment and detected cues at previously searched and unsearched locations; their cue detection RTs were measured. Unlike in typical visual search paradigms, participants in this study had to make head and limb movements in order to perform their search task. Because this task involved manual search, search rates were slower than those normally observed in IOR experiments, taking seconds instead of a few hundred milliseconds. While this virtual foraging task is quite removed from the typical IOR experiment, if IOR really functions as a foraging facilitator, then participants should be inhibited from returning their attention to previously visited locations on the virtual tree and slower to detect cues at these locations than at unvisited locations.

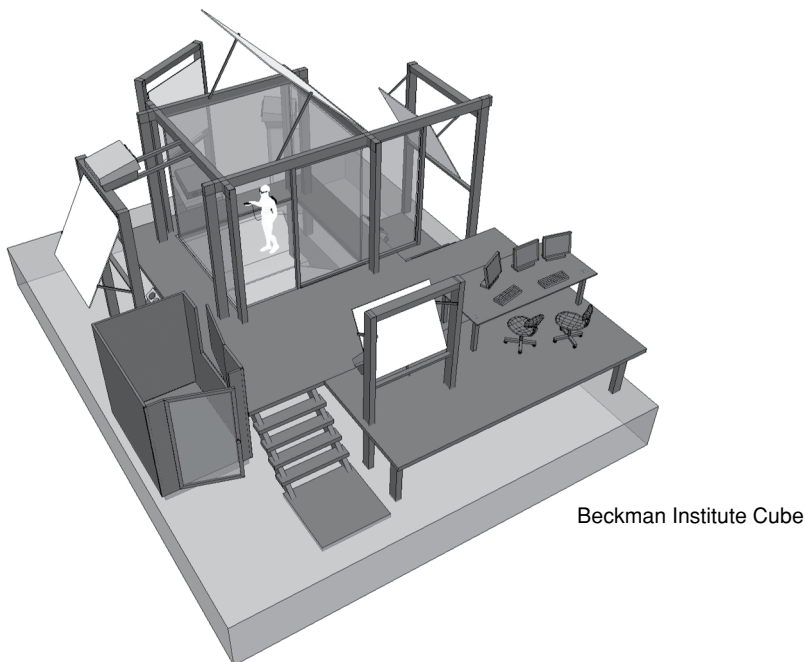
## METHOD

### Participants

Sixteen undergraduate students participated in the experiment for course credit.

### Apparatus

The experiment was conducted in the Beckman Institute Virtual Reality Cube. Figure 1 shows a schematic of this apparatus. The Cube is a 3-m<sup>3</sup> room in which all six surfaces are rear-projection screens. A PC cluster running in-house software renders stereoscopic imagery at 48 frames/sec/eye on all six surfaces, completely surrounding the participant with a virtual world. An electromagnetic tracking system (Ascension MotionStar Wireless) measured the position and orientation of the participant's head and of a custom-built two-button response box, allowing the world to be rendered correctly from the participant's point of view and permitting the



**Figure 1.** Layout of the Beckman Institute Virtual Reality Cube. Drawn by Lance Chong; copyright 2005, trustees of the University of Illinois at Urbana-Champaign.

participant to interact with the virtual objects. The response box was a component of a system for measuring RTs. At the beginning of each response interval, the red channel of the screen behind the participant would flash for a single frame at an undetectably low luminance. A microcontroller that was patched into the video cable detected the flash and started a timer. The response box also read the participant's buttonpresses; after each buttonpress the time since the preceding flash and the participant's button choice were sent to the computer running the experiment.

### Stimulus

The stimuli were 19 green virtual leaves, each approximately 21 cm across; a target consisting of three pink concentric circles, the largest 23 cm in diameter; and a yellow virtual pear  $10.5 \times 16$  cm in size. All 19 leaves appeared within an ellipsoidal volume measuring  $180 \times 180 \times 240$  cm and centered on the back wall of the Cube, with the constraint that all leaves were at least  $8^\circ$  apart. The target was positioned randomly within the same volume and subject to the same spacing constraint. A green cross 3 ft from the center of the Cube's floor indicated where the participant should stand for the duration of the experiment. A 20-ft virtual wand extended from the edge of the response box away from the participant. When the participant guided this wand to within  $5^\circ$  of an object, the object was outlined by a wire-frame rectangle, indicating that it was selected for interaction. The walls of the virtual environment were light blue and the floor was a dirt pattern.

### Design

Each participant completed one block of 200 trials. In 20 of these trials, the participants searched the leaf array until they found the fruit (*catch trials*). For the remaining 180 trials, the participants searched the array until a cue appeared at a previously searched location that was one, two, or three positions back (*old location*), or until a cue appeared at a location not previously searched (*new location*) that was at the same distance from the participant as the cue at the old location. There were 30 trials each of the six conditions (1-, 2-, and 3-back old locations and 1-, 2-, and 3-back new locations). Order of trial presentation was randomized.

### Procedure

At the beginning of a trial, the participants were presented with a pseudorandom array of 19 leaves and one target. Participants began the trial by pointing the virtual wand at the target to select it, as displayed in Figure 2, then clicking the right button on the response box. The target disappeared and participants initiated a self-paced

search of the leaf array. Participants were instructed to find a piece of fruit that was hidden behind a leaf on the virtual tree. Participants pointed the virtual wand at a leaf to select it and then pressed the right response-box button to make it swing upward, revealing whether or not the fruit was hidden behind it. Eye, head, and arm movements were necessary to complete this search. In the 20 catch trials, participants searched locations until they found the fruit, at which time they were instructed to press the left button on the response box as quickly as possible. When the fruit appeared, its luminance flickered at 16 Hz to make it more detectable. These catch trials were included to ensure that participants were motivated in their foraging task; data for these trials were not analyzed.

In the remainder of the trials, which contained no fruit, after participants had searched behind between 4 and 10 leaves (actual number was selected randomly), a leaf in the array began to flicker in luminance at 16 Hz. This flashing cue appeared either at a leaf that participants had already searched (old location) or at a leaf that had never been visited (new location). In the old condition, the cued leaf was one, two, or three positions back in the search sequence. In the new condition, leaves were selected so that their distance from the participant's current search position was approximately equal to that of a leaf searched one, two, or three positions back. This was accomplished by computing the visual angle from the last visited leaf to the *n*-back leaf, and then selecting an unvisited leaf that most closely matched this visual angle as the target. The average distance in degrees of visual angle between the last visited leaf to the *n*-back leaf was 11.47, 15.84, and 19.45 for the old condition, and 11.53, 15.77, and 19.34 for the new condition, for the 1-, 2-, and 3-back cases, respectively. Average 3-D distance in feet from the last visited leaf to the *n*-back leaf was 2.47, 2.91, and 3.35 for the old condition and 2.44, 3.10, and 3.34 for the new condition for the 1-, 2-, and 3-back cases, respectively. In addition to being instructed to search for fruit, participants were also told that as soon as they detected a flashing leaf they should press the left button on the response box. Participants' RTs in detecting the flashing cue were measured using the system described above. In the catch trials, a new trial began after participants found the fruit; in the remaining trials, new trials began after participants pressed the button in response to a flashing leaf.

## RESULTS

Trials in which a recording error occurred (2% of the trials) were dropped from analysis.<sup>1</sup>



Figure 2. Leaf array for a typical trial.

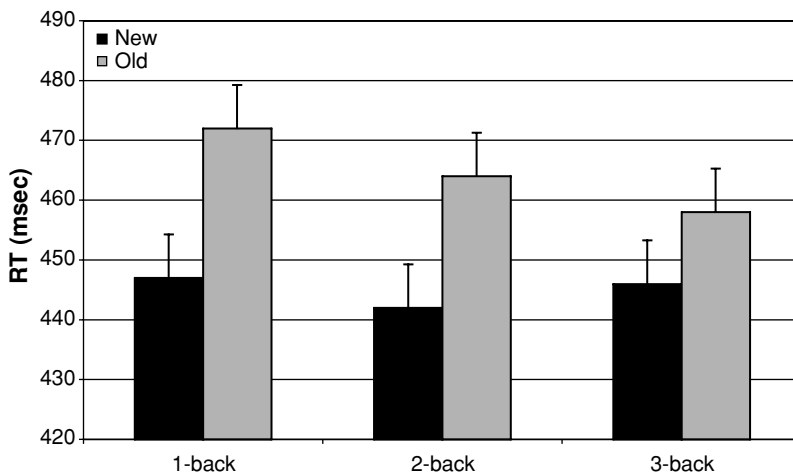
If inhibition of return is present in our foraging task, we would expect participants to be slower at detecting cues presented at previously searched locations than at unvisited locations. Figure 3 shows the mean of participants' RTs to detect cues at old locations one, two, and three positions back in the search sequence as well as to cues at distance-equated new locations. As Figure 3 shows, participants were faster to respond to flashing leaves that they had never searched than to leaves that they had already inspected. A cue type (old vs. new)  $\times$   $n$ -back (one, two, or three) ANOVA confirmed these impressions, with a significant main effect of cue type [ $F(1,15) = 6.685$ ,  $MS_e = 1,451$ ,  $p = .021$ ] and no effect of  $n$ -back [ $F(2,30) = 0.636$ ,  $MS_e = 838$ ,  $p = .536$ ] or interaction between cue type and  $n$ -back [ $F(2,30) = 0.505$ ,  $MS_e = 862$ ,  $p = .609$ ]. Paired-samples  $t$  tests conducted for the mean RTs in the old versus new conditions for each  $n$ -back case showed a marginally significant difference between old versus new conditions at 1-back [ $t(15) = -1.949$ ,  $SD$  difference = 13.301,  $p = .070$ ], a significant difference between old versus new conditions at 2-back [ $t(15) = -2.194$ ,  $SD$  difference = 10.286,  $p = .044$ ] and no significant difference between old and new in the 3-back case [ $t(15) = -1.106$ ,  $SD$  difference = 10.680,  $p = .286$ ].

## DISCUSSION

IOR has long been viewed as a foraging facilitator in visual search. Presumably, as we go about foraging tasks in our daily lives—searching for car keys on a cluttered desk, pawing through the laundry basket for a clean shirt, or scanning a crowded lobby for a friend—IOR aids our accomplishment of these tasks, preventing us from searching the same locations over and over. Although IOR is often generalized to such complex real-life examples, the vast majority of IOR studies have been based on simple visual search displays presented on computer monitors (Klein,

1988; Müller & von Mühlenen, 2000; Takeda & Yagi, 2000). A few studies have also examined IOR using eye movement measurements and more complex 2-D displays, also presented on computer monitors (Klein & MacInnes, 1999; MacInnes & Klein, 2003). Our study has gone further, demonstrating that IOR does occur in a task that more closely approximates the real-world examples described previously. When participants manually searched for fruit on a virtual tree, they were slower to detect cues at previously searched locations than at unsearched locations; that is, responses to cues at unvisited locations were consistently faster than responses to cues at locations one or two positions back in the search sequence. Our results confirm that IOR does indeed encourage orienting toward novel locations, thereby facilitating foraging.

In principle, this pattern could also result from a prospective memory strategy: the detection of cues at new locations is facilitated because participants deploy attention selectively to new locations. That is, the difference between responses to old and new locations results from attention directed to new items rather than from IOR to old items. If the prospective memory hypothesis is correct, then we should find greater facilitation as a function of proximity to the most recently attended item rather than as a function of the  $n$ -back. A linear regression predicting RT for trials from (1) the visual angle between last leaf visited and cued leaf and (2) the  $n$ -back revealed a reliable effect of  $n$ -back for old trials (estimate =  $-20.666$  msec,  $t = -2.526$ ,  $p = .012$ ) but not for new trials (estimate =  $-105.88$  msec,  $t = -0.656$ ,  $p = .512$ ) and no reliable effect of distance for either old or new trials (estimate =  $1.617$  msec,  $t = 1.598$ ,  $p = .110$ , for old trials; estimate =  $-12.98$  msec,  $t = -0.622$ ,  $p = .534$ , for new trials). (These analyses control for between-subjects variability.) Although prospective memory may contribute to these effects, the sequence in which items were searched directly predicts performance, and thus demonstrates a contribution of IOR.



**Figure 3.** Mean reaction times (RTs) to detect a flashing leaf at locations searched one, two, or three places back in the search sequence (old location) and equally distant (from the participant) unvisited leaf locations (new location). Error bars represent  $SEM$  based on the cue type  $\times$   $n$ -back  $MS_e$  term.

In addition to supporting the foraging hypothesis and extending evidence of the presence of IOR to a task that more closely approximates natural foraging, our results also shed light on the time course of IOR. In a typical IOR task, the delay between the initial stimulus and the probe is relatively short, with stable IOR effects demonstrated for stimulus onset asynchronies of 300–1,600 msec (Samuel & Kat, 2003). In typical visual search tasks, participants attend to each item for approximately 200–500 msec (see, e.g., Klein, 1988), and IOR operates in approximately the same time period. However, in the present study, participants took an average of 1.7 sec to search each item, and we found robust IOR when the cued location was two items back in the search sequence (about 3.4 sec). Thus in our task, IOR lasted almost 2 sec longer than in more traditional paradigms (see Samuel & Kat, 2003, but see Danziger, Kingstone, & Snyder, 1998; Snyder & Kingstone, 2001; and Tipper, Grison, & Kessler, 2003, for exceptions). Why was IOR longer lasting in our experiment? Perhaps the time course of IOR in a foraging task is proportional to the search rate, with inefficient searches leading to longer lasting IOR than efficient ones. This proposal is consistent with evidence that participants rarely recheck items in a manual search (Gilchrist et al., 2001). In that study, target-present searches took an average of 29 sec, so IOR may have lasted much longer at each searched location than it would have in a more efficient visual search task (Gilchrist & Harvey, 2000). Future research could examine how the time course of IOR varies as a function of search efficiency, in both visual and manual searches or foraging tasks.

Consistent with evidence that IOR occurs for multiple, successively cued or searched items or locations (see, e.g., Danziger et al., 1998; Klein & MacInnes, 1999; Snyder & Kingstone, 2000; Tipper, Weaver, & Watson, 1996), our results show that IOR in a virtual foraging task can span two locations simultaneously. This finding is not trivial; if IOR influenced only the most recently attended item in a display, its efficacy as a foraging facilitator would be limited. Evidence that IOR persisted at more than one location in our task further supports the foraging hypothesis.

In conclusion, we found IOR in a foraging task that required slow, manual searches of a virtual environment. This result adds ecological validity to the hypothesis that IOR acts as a foraging facilitator. Far from being a fragile phenomenon found only in the lab, IOR appears to be robust, long lasting, and capable of spanning multiple locations, and it occurs in tasks that approximate real-world foraging.

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## NOTE

1. A separate analysis excluded trials in which an item in the search array was selected more than once (13% of all trials). Although this number of revisitations may seem high, the rate is significantly less (all  $t_s > 23$ ,  $p_s < .001$ ) than expected in an amnesic search (see, e.g., Horowitz & Wolfe, 1998). The pattern of results was the same regardless of whether or not these trials were excluded, so we report the analyses in which they were included.