

Looking back at Waldo: Oculomotor inhibition of return does not prevent return fixations

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Inhibition of Return (IOR) is a difficulty in processing stimuli presented at recently attended locations. IOR is widely believed to facilitate foraging of a visual scene by decreasing the probability that gaze will return to previously fixated locations. However, there is a lack of clear evidence in support of the foraging facilitator hypothesis during scene search. The original R. M. Klein and W. J. MacInnes' (1999) Where's Waldo study reported a forward bias in the distribution of fixations that was taken as evidence for the foraging facilitator hypothesis. The present study was designed to replicate R. M. Klein and W. J. MacInnes' (1999) but include detailed analysis of fixation distributions in order to test the precise predictions of the foraging facilitator hypothesis. The results indicate that latencies of saccades returning to 1-back (and possibly 2-back) locations during visual search are elevated. However, there is no evidence that the probability of returning to these locations is significantly less than control locations. Eye movement behavior during search of visual scenes does not support the view that IOR facilitates foraging.

Keywords: eye movement, real-world scene, inhibition of return, fixation duration, saccadic momentum

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Introduction

Everyday life is filled with a succession of visual search tasks. Whether it is searching for your favorite shirt in your closet, your keys in a cluttered kitchen, a pen on your desktop or a face in a crowd, you shift your attention around the scene in order to find what you are looking for. To search efficiently, some record of where attention has been allocated within the scene needs to be maintained if you are to distribute your attention effectively. One process proposed to fulfill this function is Inhibition of Return (IOR).

IOR is a decrease in processing efficiency for stimuli presented at recently attended locations. The classic demonstration of IOR is a delay in responding to a target presented at a previously attended location compared to a new distance-matched location (Posner & Cohen, 1984). Since its initial demonstration in attentional cuing studies, IOR has also been observed in complex viewing tasks requiring eye movements such as visual search (Klein, 1988; Klein & MacInnes, 1999), reading (Rayner, Juhasz, Ashby, & Clifton, 2003; Weger & Inhoff, 2006), auditory and manual reaction tasks (Spence & Driver, 1998; Tassinari & Berlucchi, 1995), and search in 3D environments (Thomas et al., 2006). It has been proposed that this delay in response or *temporal* effect may facilitate visual search by “repelling attention” away from previously attended locations to help observers avoid reinspecting

them (pg. 346; Klein & MacInnes, 1999). This would result in a decrease in the probability of returning the eyes to a location once it has been fixated (Klein & Hilchey, *in press*; Wang & Klein, 2010). If IOR can be shown to have such a *spatial* consequence it can be said to *facilitate foraging* (Klein, 1988; Klein & MacInnes, 1999).

In order for the foraging facilitator hypothesis to be supported by eye movement behavior during a search task, eye movements returning to previously attended locations need to exhibit both a delay (temporal evidence) and a lower rate of occurrence compared to control locations (spatial evidence). Belief that IOR facilitates foraging currently permeates the visual attention and search literature (as evidenced by its broad incorporation into models of visual attention, e.g. Itti & Koch, 2001; Navalpakkam & Itti, 2005; Parkhurst, Law, & Niebur, 2002; Pomplun, Reingold, & Shen, 2003; Rao, Zelinsky, Hayhoe, & Ballard, 2002; Sun, Fisher, Wang, & Gomes, 2008; Zelinsky, 2008). The functional interpretation of IOR during search is highly attractive to researchers attempting to model search behavior because the simple application of inhibitory tags to previously attended locations ensures sequential scanning of candidate locations. However, empirical evidence supporting the hypothesis that IOR facilitates foraging is sparse. Currently, the only source of both temporal and spatial evidence of IOR during complex scene search comes from one study: Klein and MacInnes' (1999) Where's Waldo study.

In Klein and MacInnes (1999), participants were shown cluttered, densely populated illustrations taken from the popular collection of Where's Waldo children's books (Handford, 2008). Each scene contained a distinctly dressed character known as Waldo who participants were instructed to locate. While participants were searching the scene, a probe (a small black ring) appeared at either the previous fixation location (1-back), the penultimate fixation location (2-back), or the same distance away at new locations. Participants were instructed to fixate the probe as soon as it appeared. Saccadic reaction times to these probes indicated that saccades back to prior fixation locations took longer than saccades 180° away (although only the delay relative to the 2-back location reached significance). Klein and MacInnes (1999) also showed that saccades prior to the probe presentation tended to be directed away from previously fixated locations. In combination, they took these results as both temporal and spatial evidence that IOR facilitates foraging.

Since the Klein and MacInnes (1999) study was published, several scene viewing studies have replicated the temporal evidence of IOR for return saccades to 1-back locations (Hooge, Over, van Wezel, & Frens, 2005; MacInnes & Klein, 2003; Smith & Henderson, 2009a, under review) and 2-back locations (Dodd, Van der Stigchel, & Hollingworth, 2009), but there has been no evidence of the predicted spatial consequence of IOR. The probability of voluntarily returning to the 1-back location has been shown to be significantly greater than chance during search (Hooge et al., 2005; Smith & Henderson, under review) and free-viewing (Hooge et al., 2005), and equal to the fixation probability at distance-matched locations during memorization (Smith & Henderson, 2009a) and search (Smith & Henderson, under review). There is also no evidence for a decrease in the probability of fixating sudden-onset probes at the 1- or 2-back locations (Smith & Henderson, 2009a, under review). In fact, attention capture by sudden-onset probes at 1- and 2-back locations during scene memorization may even be facilitated (Smith & Henderson, 2009a).

One potential reason for the difference between the findings of Klein and MacInnes (1999) and subsequent studies (Hooge et al., 2005; Smith & Henderson, 2009a, under review) could be the precision of the analyses. Klein and MacInnes (1999) identified the spatial consequence of IOR by comparing the proportion of saccades directed back in the direction of the 1-, 2-, and 3-back locations to saccades directed 180° away. The large angular deviation bins used in their analyses may have obscured the spatially specific return fixations reported using much more precise analyses (Hooge et al., 2005; Smith & Henderson, 2009a, under review). An alternative explanation for the different return probabilities across studies could be that differences in task, stimulus, and viewing conditions influenced the degree to which spatial IOR was expressed. A recent cross-task scene viewing

study reported a similar variable expression of temporal IOR across task (Dodd et al., 2009), though this influence of viewing task on temporal IOR has subsequently been questioned (Smith & Henderson, 2009b, under review).

In the present study we replicated the Klein and MacInnes (1999) Where's Waldo paradigm and analyzed the data using the more precise analysis methods of Smith and Henderson (2009a, under review) in order to clarify the spatial influence of IOR on fixation probability during search.

Methods

Participants

Thirty-four members of the Edinburgh University community participated for payment. Participants were randomly allocated to one of two sudden-onset probe conditions: 1-back (the probes appeared relative to the previous fixation location) or 2-back (probes appeared relative to the penultimate fixation location).

Apparatus

Eye movements were monitored by an SR Research Eyelink 1000 eyetracker. Viewing was binocular, but only the right eye was tracked. The images were presented on a 21 inch Viewsonic CRT monitor (140 Hz) at a viewing distance of 90 cm.

Stimuli

Participants were presented 54 unique full-color 1024 × 768 pixel (subtending 25.7° × 19.4° visual angle) 32 bit Where's Waldo illustrations scanned and cropped from the Solid Gold Collection (Handford, 2008). All images depicted a highly cluttered scene containing many background and foreground elements and human figures (see Figure 1). Each scene contained a distinctively dressed character called Waldo who functioned as the search target (red circle, Figure 1). The size of Waldo varied from scene to scene but generally occupied an area 1 to 2 deg in diameter. Each scene contained many distracter elements including people wearing similar clothes. The distracters made the search task very difficult.

Procedure

The procedure was a close replication of Klein and MacInnes (1999). Participants were given two tasks:

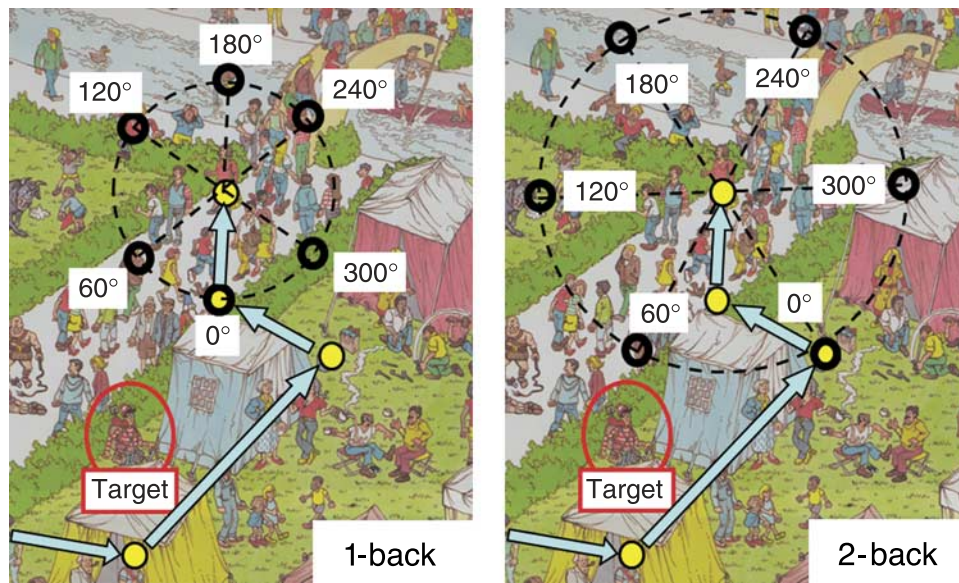


Figure 1. An example of the stimuli used in the study and sequence of events. Participants were instructed to search the scene for Waldo (red ellipse; not shown to participants). They terminated the trial as soon as they located Waldo. After 1200 ms of scene presentation (yellow circles indicate fixations) the fixation marker reappeared during a fixation at one of six locations on a circle around the current fixation and radius equal to the distance to the previous fixation (1-back; left image) or penultimate fixation (2-back; right image). Participants were instructed to fixate the marker as soon as it appeared. The marker disappeared as soon as it was fixated and participants were permitted to continue their search for a total of 30 seconds before trial termination. Original images taken from Handford (2008).

1) search the scene for Waldo and press a button as soon as he is located, and 2) fixate a probe as soon as it appears on the screen. Each trial began with a fixation marker presented along with the search scene. The marker was a small black ring (0.63° diameter with 0.33° transparent center) located at screen center. The marker remained on the screen for 700 ms during which time the participants were instructed to hold fixation and only begin searching for Waldo after the marker disappeared. Participants had 30 s to search the scene before it timed-out and the next trial began. If they located Waldo during this time they responded by pressing a button on the joystick (Microsoft Sidewinder).

After 1200 ms of scene presentation, the sudden-onset probe was abruptly presented during a fixation (about 40 ms after the start of the fixation) in one of six locations on the circumference of a circle with its origin at the current fixation point and radius equal to the distance from the previous fixation (1-back; Figure 1, left image) or penultimate fixation (2-back; Figure 1, right image). The sudden-onset probe was physically the same as the fixation marker. The angular deviation of the probe location from the 1-back or 2-back location was 0° , 60° , 120° , 180° , 240° , or 300° (see Figure 1). If the distance to the penultimate fixation was less than 1° or any of the potential sudden-onset probe locations fell off the screen, the program waited until the next suitable fixation in which all potential onset locations fell on the screen. Participants were instructed to fixate the probe as soon as it appeared. The probe disappeared as soon as it was

fixated. After the probe disappeared search continued until participants pressed a button indicating they had located Waldo, or until 30 s had elapsed.

Results

Search performance

Before investigating the presence and impact of oculomotor IOR on eye movements, performance in the Where's Waldo search task was assessed. As expected, participants found locating Waldo very difficult but not impossible. Mean success rate was 71% with an average search time of 9.2 s. There were no significant differences between the 1-back and 2-back groups. The sudden-onset probe was presented 3.7 s and 12.7 fixations into each trial on average, making the timing of the probe equivalent to the original Klein and MacInnes (1999) study. The delay in probe presentation for 2-back was due to the difficulty in ensuring all locations fell on the screen. Probe location chosen for each trial had no effect on search performance.

Time taken to return

To examine whether IOR delays reorienting to previously fixated locations, the time taken to program

saccades to sudden-onset probes at the 1-back and 2-back locations was compared to the time taken to program saccades to probes at the five control locations (60°, 120°, 180°, 240° and 300°). The mean distance from fixation to probes at 1- and 2-back was 3.98° ($SD = 1.06$) and 3.87° ($SD = 0.89$), respectively with no difference across probe locations. Only saccades landing within 1.5° of the six target locations were used in the analysis, ensuring that hits for each probe location did not overlap. The distance to probes that were immediately fixated was significantly shorter (mean = 3.28, $SD = 1.02$) than to probes that were missed (mean = 4.52, $SD = 1.55$, $F(1, 31) = 82.97$, $MSE = 101.3$, $p < 0.001$), with no effect of whether the probe was 1- or 2-back or probe location. The difference between hits and misses was probably due to decreasing visibility of the probe with increasing eccentricity. Saccadic latencies to the probes were averaged across 60°/300° and 120°/240° to investigate whether there was a linear effect of angular deviation. Given that the probe always appeared about 40 ms into a critical fixation, the duration of the critical fixation (fixation duration) was used as a proxy for saccadic latency. Mean fixation durations are displayed in Figure 2.

A repeated-measures ANOVA of preceding fixation durations with within-subjects factor Location (0°, 60°/300°, 120°/240°, and 180°) and between-subjects factor Back (1-back vs. 2-back) indicated a main effect of Location, $F(3, 96) = 3.426$, $MSE = 1652$, $p < 0.05$, a main effect of Back, $F(1, 32) = 4.178$, $MSE = 5898$, $p < 0.05$, but no

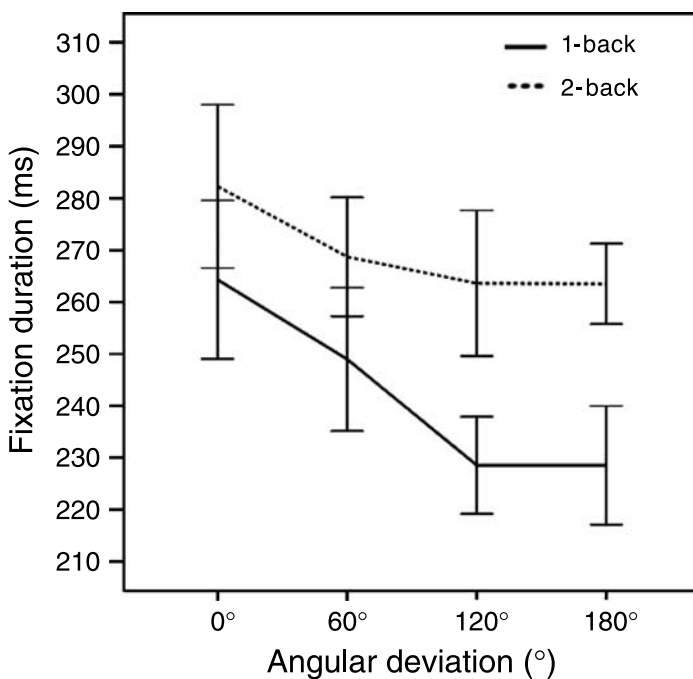


Figure 2. Mean fixation duration (ms) preceding a saccade hitting onsets at the four locations (0°, 60°, 120°, 180°) relative to the previous fixation (solid line) and penultimate fixation (dotted line). Error bars represent ± 1 standard error.

interaction, $F < 1$. Across both Back conditions, saccades to probes at previous fixation locations (0°) were preceded by significantly longer fixations (mean = 273 ms, $SD = 63.6$) than saccades to probes at 120°/240° (mean = 246 ms, $SD = 51.6$, $p < 0.05$), and 180° (mean = 246 ms, $SD = 43.4$, $p < 0.01$). The difference between 0° and 180° suggests an IOR effect of 27ms. Saccades to probes at 60°/300° (mean = 259 ms, $SD = 52.3$) were also preceded by significantly longer fixations than saccades to probes at 180° ($p < 0.05$). There were no other significant differences. The pattern of fixation durations across probe locations cannot be accounted for by variation in the eccentricity of the probes given that the mean eccentricity of the probes did not vary across probe locations. These results confirm the linear relationship between angular deviation and preceding fixation duration observed in previous studies (Klein & MacInnes, 1999; MacInnes & Klein, 2003; Smith & Henderson, 2009a, under review).

The absence of an interaction with Back suggests that the pattern of increasing preceding fixation durations with angular deviation of probe was similar across 1- and 2-back. However, quantitatively the IOR effect was larger for 1-back (mean difference = 36 ms) than for 2-back (mean difference = 19 ms). It is unclear why the observed delay for the 2-back location was not as large as in the original Klein and MacInnes (1999) study, but given the near identical nature of the stimuli and experimental conditions, the difference in IOR effect for the 2-back location was probably due to the greater intrinsic variability in the angle and amplitude of the saccade required to take the eyes back to the 2-back compared with the 1-back location. Importantly, the main effect of probe location across both 1- and 2-back locations indicates that return eye movements experience delay relative to forward saccades. This delay is characteristic of oculomotor IOR during scene viewing (Dodd et al., 2009; Hooge et al., 2005; Klein & Hilchey, in press; Klein & MacInnes, 1999; MacInnes & Klein, 2003; Smith & Henderson, 2009a, under review).

Distribution of saccades

Having confirmed the temporal IOR effect for saccades directed back to previously fixated locations, we can pose the main question of interest in this study: What influence does temporal oculomotor IOR have on fixation probability? According to the foraging facilitator hypothesis, IOR biases fixations away from locations that have recently been fixated. However, the only evidence supporting this hypothesis to date comes from the two Where's Waldo studies of Klein and MacInnes (1999; MacInnes & Klein, 2003). This evidence came from an analysis in which all saccades during the normal search period (that would have permitted the presentation of probes) were classified in terms of their angular deviation from the previous saccade. This analysis of the distribution

of saccades indicated a tendency for saccades to continue along the same trajectory rather than to reverse trajectory.

Performing a similar analysis of saccade distributions on the present data revealed a similar forward bias (Figure 3). All saccades during the search period (i.e. not immediately following the onset probe or after Waldo had been fixated) that would allow the presentation of the probe, were classified according to their angular deviation from the saccade that would take the eyes back in the direction of the 1-back or 2-back location. After all exclusions, 39,590 saccades relative to the 1-back location and 13,644 saccades relative to the 2-back location remained. As can be seen in Figure 3, there was a clear tendency for saccades to be directed away from the previous fixation location (1-back: $F(3, 48) = 86.76$, $MSE = 0.001$, $p < 0.001$) and penultimate fixation location ($F(3, 48) = 13.28$, $MSE = 0.001$, $p < 0.001$). However, what is unclear from this analysis is whether this distribution of saccades is due to inhibition of regressive saccades or facilitation of forward saccades. Closer examination of the saccade probabilities revealed that regressive saccades occurred significantly less than forward saccades (1-back: difference = 0.11, $p < .001$; 2-back: difference = 0.05, $p < 0.01$) but significantly more than saccades directed $60^\circ/300^\circ$ away (1-back: difference = 0.06, $p < 0.001$; 2-back: difference = 0.017, $p < 0.05$). This increased frequency of regressive saccades compared to directions other than forward would not be expected if the forward bias was caused by IOR, and is more consistent with a tendency for the eyes to move forward (*saccadic momentum*, Smith & Henderson, 2009a) rather than a tendency for them not to move backward. However, the coarseness of this analysis presented here and in previous studies (Klein & MacInnes, 1999; MacInnes & Klein, 2003) does not allow the precise predictions of the foraging facilitator hypothesis to be tested. More precise analysis of the spatial distribution of fixations is required to determine the influence of spatially specific oculomotor IOR on fixation probability at the specific location of previous fixations.

Distribution of fixations

If the temporal IOR experienced at previously fixated locations facilitates foraging during normal scene search, we should observe significantly fewer saccades returning to previously fixated locations than to control locations. It is unclear whether the forward bias in saccades presented above and previously (Klein & MacInnes, 1999; MacInnes & Klein, 2003) is due to spatially specific IOR at prior fixation locations (Hooge & Frens, 2000; Smith & Henderson, 2009a) or a tendency to repeat saccade programs, i.e. *saccadic momentum* (Smith & Henderson, 2009a). If IOR has a spatial effect on subsequent saccade programs it should be evident as a spatially specific decrease in the probability of fixations landing at prior fixation locations, not just an overall forward bias. The

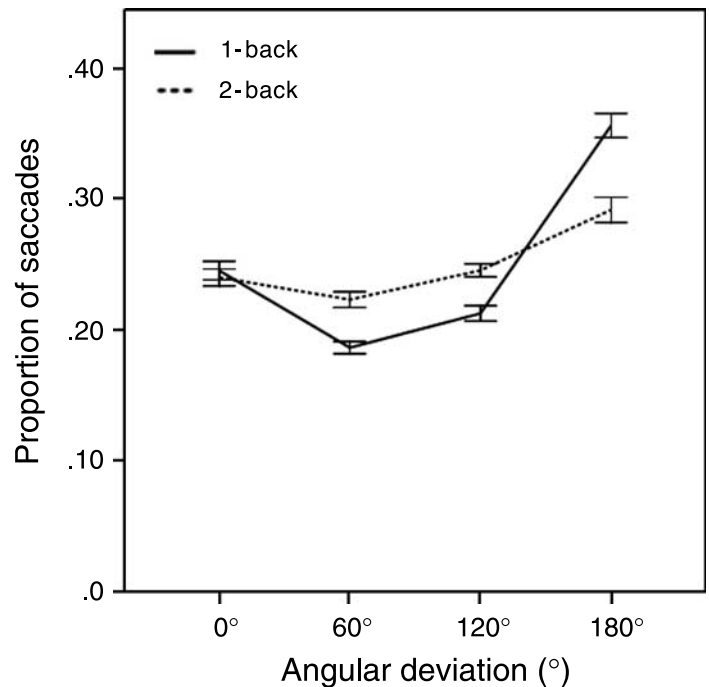


Figure 3. Distribution of saccades relative to previous fixation locations (1-back, solid line; 2-back, dotted line) during the search period. Saccades are binned according to their angular deviation from the saccade that would take them back in the direction of the previous fixation location (0°).

distribution of saccades presented in Figure 3 may hide this spatially specific effect due to averaging across saccades of all amplitudes in a particular direction.

To look for a spatially specific consequence of IOR in the present data, all saccades with amplitudes greater than 1° during the normal search period (i.e. not following an onset or after the first fixation on the target) were classified in terms of their angular deviation from the 1-back or 2-back fixation location (Figure 4, circumference values). Saccades were further classified according to the difference between their amplitude and the amplitude of the previous saccade (Next-1-back) or the distance to the penultimate location (Next-2-back, Figure 4; radial values). The colors in Figure 4 represent the fixation probability for each location; precise return to a prior fixation location has a value of $0^\circ/0^\circ$ (heatmaps are inspired by the visualizations used by Hooge et al., 2005 and Motter & Belky, 1998). Both of the 1- and 2-back fixation probability distributions clearly demonstrate an overall forward bias in saccades: the lighter cells to the right of each figure signify that the majority of fixations occur 140° to 220° away from 1-back and 2-back locations at a distance similar to the prior locations ($\pm 2^\circ$). As demonstrated above, the fixation probabilities decrease as angular deviation decreases (i.e. approaches 0°). However, contrary to the prediction of the foraging facilitator hypothesis, there was not an absence of fixations or noticeable decrease in the fixation probability

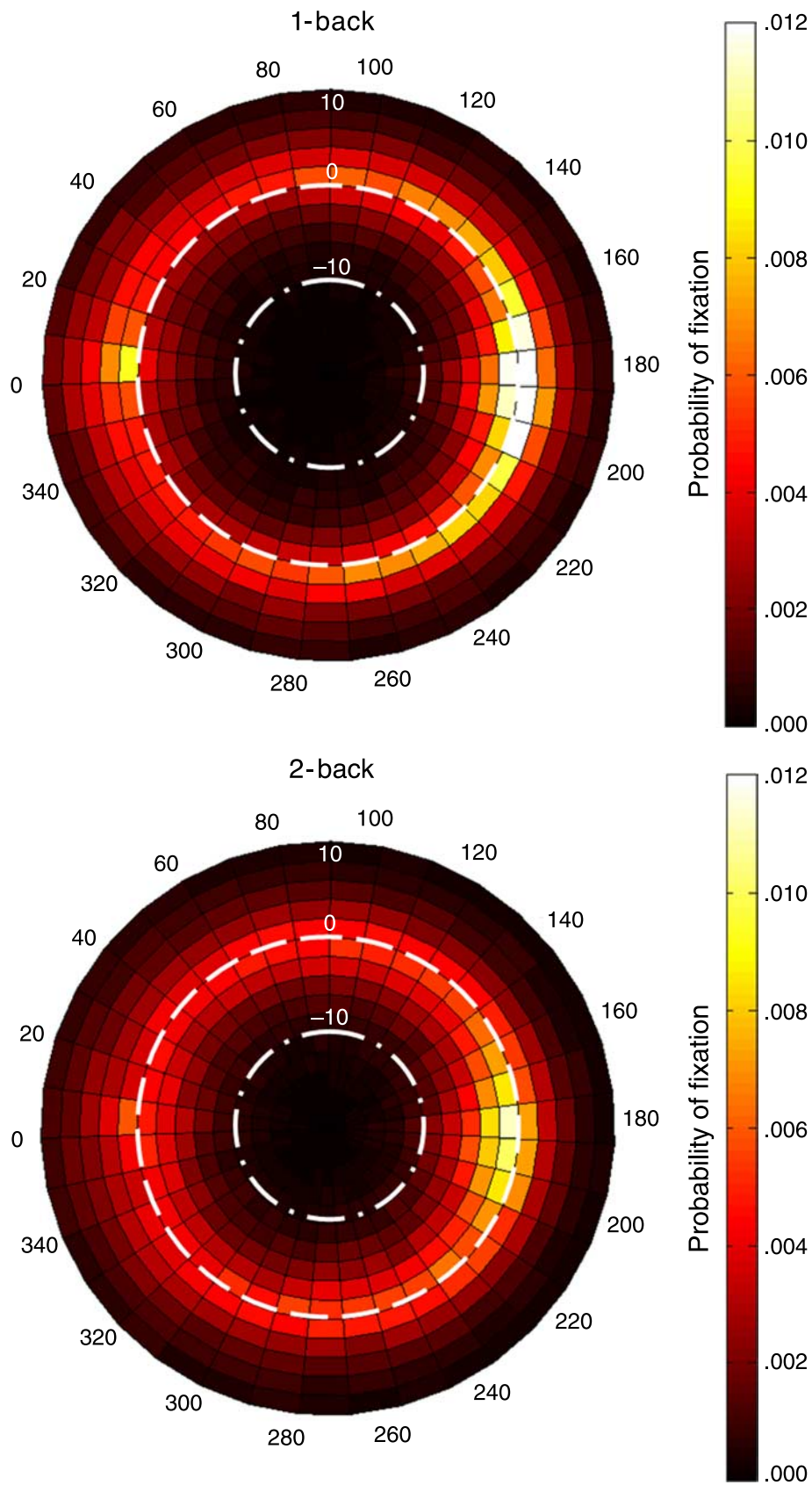


Figure 4. Distribution of fixations during search relative to previously fixated locations (Top = 1-back, Bottom = 2-back) and current fixation (center of each figure). Locations categorized by Angular Deviation from previous location (circumference, 10° bins) and Difference in Saccade Amplitude (Next–distance to 1 or 2-back; rings, 2° bins). Colors indicate probability of fixation.

at the 1- or 2-back locations. Instead, contrary to the foraging facilitator hypothesis, the probability of fixating 1- and 2-back locations appeared to be greater than surrounding locations (see the yellow cell at $0^\circ/0^\circ$ in Figure 4, Top, and orange cell at $0^\circ/0^\circ$ in Figure 4, Bottom). This may be evidence of the spatial Facilitation of Return demonstrated during scene memorization (Smith & Henderson, 2009a).

Spatially specific fixation probability

To quantify for statistical analysis the return probabilities illustrated in Figure 4, the probability of returning to prior locations (1- and 2-back) during search (i.e. not immediately following an onset or after Waldo had been fixated) was compared to the distance-matched control locations (60° , 120° , 180° , 240° , 300° ; see Figure 1). Probabilities were averaged across $60^\circ/300^\circ$ and $120^\circ/240^\circ$. The fixations used in this analysis satisfied all the conditions for probe presentation (see Figure 1) except no probe was present. Mean fixation probabilities are shown in Figure 5.

Fixation probabilities exhibited a significant forward bias relative to both 1-back ($F(3, 48) = 5.507$, $MSE = 0.001$, $p < 0.01$) and 2-back fixation locations ($F(3, 48) = 7.294$, $MSE = 0.001$, $p < 0.001$). However, the main effect of Location was not due to a lower probability of return

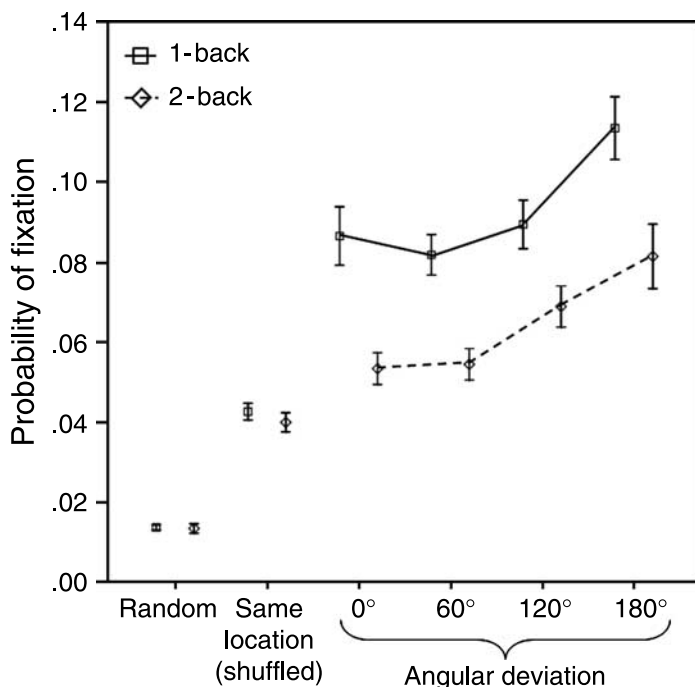


Figure 5. Mean fixation probabilities during normal search for the 1-back (0° ; squares, solid line) or 2-back locations (0° ; diamonds, dashed line), distance-matched control locations (60° , 120° , 180°), and the 1-back or 2-back location when order effects are eliminated (Shuffled). Chance fixation probability is also displayed (Random). Error bars represent ± 1 standard error.

fixations, but rather a greater probability of fixating 180° away from previous locations. The probability of returning to the 1-back location (mean = 0.086, $SD = 0.03$) was not significantly different from the $60^\circ/300^\circ$ (mean = 0.082, $SD = 0.02$) or $120^\circ/240^\circ$ locations (mean = 0.089, $SD = 0.03$). The only location with a significantly greater fixation probability was 180° (mean = 0.113, $SD = 0.03$; difference = 0.027), which was greater than all other locations (all $ps < 0.05$). A similar bias to fixate the 180° location seems to account for the main effect of Location relative to 2-back. The probability of returning to the 2-back (mean = 0.053, $SD = 0.016$) and $60^\circ/300^\circ$ locations (mean = 0.054, $SD = 0.016$) were both significantly less than the $120^\circ/240^\circ$ (mean = 0.069, $SD = 0.021$, $ps < 0.05$) and 180° locations (mean = 0.081, $SD = 0.033$, $ps < 0.01$), with no significant difference between them.

In sum, analysis of the probability of returning to 1- and 2-back locations does not indicate a spatially specific decrease in fixation probability relative to other distance-matched locations. The only location exhibiting a greater fixation probability is 180° (and 120° relative to 2-back) and this may be due to facilitation of forward saccades rather than inhibition of return saccades (for further discussion of the distinction see Smith & Henderson, under review).

The present analysis controlled for eccentricity of saccade targets. However, such controls have been criticized for not controlling for the content at each location and its relevance to the search task (Klein & Hilchey, in press; Wang & Klein, 2010). It has been suggested that the probability of fixating prior locations should be compared to the probability of fixating the same location when it has not previously been fixated. Locations that are more relevant to the viewing task will have a higher initial fixation probability and subsequently receive more fixations. This higher “baseline” may obscure any decrease in fixation probabilities for previously visited locations when compared to potentially irrelevant but distance-matched control locations.

To create a baseline in the current data that controlled for content relevance, the actual fixations produced by each participant on each trial were shuffled fifty times. By shuffling within participants, individual attentional control settings are controlled. Averaging across fifty repetitions of the shuffling eradicates noise and creates a constant baseline of return probability. Shuffling the sequence of fixations preserves the number of times a location is fixated but order effects, such as IOR or proximity, are eradicated (Hooge et al., 2005). The probability that 1- and 2-back fixations occur in these new shuffled sequences are then calculated and compared to the actual return probabilities. If IOR at prior fixation locations affects the probability of return, 1- and 2-back fixation probabilities should be significantly lower than this shuffled baseline.

The probability of fixating the 1-back location in the actual data (mean = 0.086, $SD = 0.03$) was significantly greater than the probability of fixating the same location

when order effects were eliminated (mean = 0.042, $SD = 0.009$, difference = 0.044, $p < 0.001$; see Figure 5, Shuffled-squares). The probability of fixating the 2-back location (mean = 0.053, $SD = 0.016$), while lower than 1-back location, was also significantly greater than the shuffled control (mean = 0.040, $SD = 0.01$, difference = 0.013, $p < 0.01$; see Figure 5, Shuffled-diamonds). As can be seen from Figure 5, the probability of fixating the shuffled control was significantly greater than chance (the probability of landing within 1.5° of a randomly selected location on the screen; mean = 0.013, $SD = 0.005$, $p < 0.001$), confirming that only a limited number of screen locations are fixated during search and this cycling through limited locations is captured by the shuffled baseline.

In sum, analysis of fixation probabilities during search indicates that even when eccentricity and content are controlled, the probability of returning to 1- and 2-back fixation locations is at least as high as most control locations. The only location exhibiting higher fixation probability is 180° away from 1 and 2-back locations, and this forward bias may be due to a tendency to repeat saccade programs rather than to oculomotor IOR. There is no evidence that IOR at 1- or 2-back locations decreases fixation probability during Where's Waldo search.

General discussion

This study investigated whether Inhibition of Return (IOR) facilitates foraging during scene search. By replicating the seminal Klein and MacInnes (1999) Where's Waldo study but adding detailed analysis of the distribution of fixations relative to previously fixated locations (1- and 2-back), we were able to show that return fixations occurred significantly more than would be expected if IOR at these locations facilitated foraging. Return fixations occurred significantly more than would be predicted by chance and as often (but not less often) as at other distance-matched locations during normal search. We replicated previous evidence of temporal delay immediately prior to saccades returning to onset probes at previous fixation locations (Dodd et al., 2009; Hooge et al., 2005; Klein & MacInnes, 1999; MacInnes & Klein, 2003; Smith & Henderson, 2009a, under review), but showed that the presence of temporal IOR does not necessarily mean that IOR also has a spatial consequence decreasing the probability of return. Without evidence for both a temporal and spatial consequence of IOR, we argue that the foraging facilitator hypothesis is not supported.

Why do we find such a high percentage of return fixations during scene search (8.6%) when previous studies have reported return probabilities lower than chance (Boot, McCarley, Kramer, & Peterson, 2004; Dickinson & Zelinsky, 2005; Gilchrist & Harvey, 2000; McCarley, Wang, Kramer, & Irwin, 2003; Peterson, Kramer, Wang,

Irwin, & McCarley, 2001)? One of the main differences between our study and previous studies is the complexity of stimuli and processing required during each fixation. All studies demonstrating return probabilities lower than chance used very sparse search arrays or saccade targets requiring simple discrimination (Boot et al., 2004; Gilchrist & Harvey, 2000; McCarley et al., 2003; Peterson et al., 2001). When the discrimination task (Dickinson & Zelinsky, 2007; Motter & Belky, 1998; Peterson et al., 2001) or object/scene complexity increase (Hooge et al., 2005; Smith & Henderson, 2009a, under review), return probability has been shown to increase to above chance level. With more complexity, processing of foveal information may not have been completed during a single fixation, necessitating a return saccade for a second look.

The utility of return saccades may also vary across environments in order for viewers to be sensitive to the demands of the specific environment and distribute their attention optimally. In a recent study, Farrell, Ludwig, Ellis, and Gilchrist (2010) manipulated the frequency with which return saccades were cued to new or old locations. They found that temporal evidence of IOR disappeared when participants were repeatedly presented trials with a high probability of return. This result, along with the findings of the current study, suggest that the expression of temporal and spatial IOR may both be sensitive to stimulus factors and task demands.

A similar positive relationship between processing difficulty and return probability is also observed in reading (Rayner & Pollatsek, 1989; Vitu, 2005). On average, 10–15% of all reading fixations are regressions (Rayner, 1998), with the regression likelihood increasing with text difficulty, ambiguity, and lower reading ability (see Vitu, 2005 for review). Regressions are believed to be highly functional, allowing the reader to re-examine words in order to resolve difficulties in identification and comprehension (Vitu, 2005; Vitu & McConkie, 2000), and good readers are very accurate at sending their eyes directly back to the source of the difficulty (Frazier & Rayner, 1982; Kennedy & Murray, 1987). The frequency and accuracy of regressive eye movements during reading suggest that readers are constantly monitoring their own processing of the text, and if they detect failures in processing they are able to directly override on-going saccade programs (such as to move to the next word to the right in English) and return their eyes to the source of the difficulty. Such regressions are subject to the same temporal IOR as experienced during visual search (Rayner et al., 2003), but the need to return appears to outweigh the difficulty in doing so. Our evidence of above-chance return probabilities suggests that similar process monitoring may be occurring during scene viewing.

The processing required during each fixation in scene search is much more complex than during reading. In reading, the task of choosing and programming the next saccade is relatively straightforward due to systematic layout of the text, whereas in scenes presented on a

computer monitor, the eyes can go in any direction and any distance within the limits of the screen. Also, search behavior in visual scenes should not be viewed as comparable to the search of simple object arrays, because search in scenes is less systematic and influenced by many features of the scene. For example, search behavior in scenes is both obstructed by factors such as difficult figure/ground separation, visual clutter (Henderson, Chanceaux, & Smith, 2009), and occlusion, and aided by scene context and object semantics (e.g. Henderson, Malcolm, & Schandl, 2009; Malcolm & Henderson, 2009, 2010). Where's Waldo is designed to be a difficult search task that involves concentrated interrogation of minute figures distributed across the entire scene (see Figure 1). Participants can use heuristics to aid their search, such as the red and white stripes on Waldo's T-shirt. However, when a time limit is imposed the complexity of processing each candidate location may mean that visual processing may not be complete before the eyes leave that location (e.g. Henderson & Smith, 2009). MacInnes and Klein (2003) showed that immediately prior to detection of Waldo, return saccades were more likely than forward saccades. They interpreted this as evidence of process monitoring combined with preprogrammed saccades that left the target location before the target had been identified (MacInnes & Klein, 2003). In such instances, the need to return outweighed the contribution from IOR. Given the frequency of precise return fixations observed in the present study and other scene viewing tasks (Hooge et al., 2005; Smith & Henderson, 2009a, under review) it appears that such instances occur throughout scene viewing. Future research should focus on identifying the local factors (e.g. foveal and parafoveal processing, preceding/subsequent saccade metrics) and global factors (e.g. viewing task, stimulus complexity and dynamics) that influence saccade programming along with the mechanism by which these factors are combined (e.g., Ludwig, Farrell, Ellis, & Gilchrist, 2009). Inhibition of saccade programs back to previously attended locations may influence the occurrence of returns but only in the absence of all other factors influencing return probability such as process monitoring, scene factors (listed above), systematic eye movement biases (Tatler & Vincent, 2008), compositional factors (Tatler, 2007), and relevance of scene content to viewing task (Henderson, Malcolm et al., 2009). During scene viewing the combination of all these factors outweigh any contribution IOR might have on the distribution of fixations within the scene. Saccades back to the previous fixation location may experience delay due to IOR, but if there is a need for the eyes to go back, they will.

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