Published in final edited form as:
Acta Psychol (Amst). 2019 May 10; 197: 32–38. doi:10.1016/j.actpsy.2019.04.017.

Post-search IOR: Searching for inhibition of return after search

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Abstract

Previous research has indicated that Inhibition of return (IOR) supports visual search by discouraging the re-inspection of recently inspected items during search. However, it is not clear whether IOR persists after a search is completed or whether this depends on the presence of a further search in the same display. To investigate this issue, we had participants search consecutively twice in the same display (Experiment 1). Immediately after the end of the first search and after the end of the second search we probed an item which had been recently inspected or not in the previous search. The results showed that IOR as measured by the saccadic latency to the probed items was absent after the end of each of the two successive searches. In Experiment 2, we measured both saccadic latencies and manual responses in a single-search paradigm. We found that IOR during and after the search was present for saccadic responses but absent for manual responses. This suggests that IOR during and after a visual search depends on the modality of the response and the number of required searches.

Keywords

Visual search; Inhibition of return; Saccadic response; Manual response

1 Introduction

When we search for a target object in our visual environment (e.g., the car keys in the living room), we probably want this search to be very efficient such that we can complete the search (i.e., find the target) successfully in the shortest possible time. Previous research has revealed that processes such as memory can make search more efficient (Geyer, von Mühlenen, & Müller, 2007; Gilchrist & Harvey, 2000; Höfler, Gilchrist, & Körner, 2014; Höfler, Gilchrist, & Körner, 2015a; Körner & Gilchrist, 2007; Körner & Gilchrist, 2008; Peterson, Kramer, Wang, Irwin, & McCarley, 2001). One further mechanism that has been

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Declarations of interest
None.

shown to improve search efficiency is inhibition of return (IOR). Due to IOR, previously inspected objects are discouraged from immediately being searched again (Klein, 1988; Klein, 2000; Wang & Klein, 2010) and, as a consequence, search is guided to a set of previously uninspected objects that will, most likely, contain the target.

The effect of IOR is typically reflected in longer saccadic latencies when a saccadic response to a previously inspected as compared to a non-inspected item is required. For instance, among the first researchers to demonstrate IOR in visual search were Klein and MacInnes (1999) (see also MacInnes & Klein, 2003). They presented a probe in the display while participants were searching through a complex scene and participants were instructed to interrupt search and saccade to the probe once they recognized it. The results indicated that saccadic IOR was active during the search: Klein and MacInnes (1999) observed longer saccadic response times to probes presented at previously fixated locations compared to probes at new locations. Because in this way IOR guides search to non-inspected objects, Klein and MacInnes (1999) proposed IOR to be a “foraging facilitator” in visual search (but see Hooge, Over, van Wezel, & Frens, 2005). Previous research also suggested that IOR lasts for the five recently inspected items only (Snyder & Kingstone, 2000) and that the amount of inhibition decreases the longer back the object was inspected (e.g. Boot, McCarley, Kramer, & Peterson, 2004).

Inhibition of previously inspected items might be functional as long as a search is ongoing because this increases search efficiency. However, this is no longer the case once a search is completed. When Klein (1988) first investigated the role of IOR with respect to visual search, he presented a luminance probe *after* participants had searched once through a search display. The probe was either presented at a position where a search item had been located before (on-probe) or not (off-probe). The results showed that it took participants longer to respond to an on-probe compared to an off-probe via a button press, suggesting that the mechanism of IOR was still active although the search was completed. However, other findings indicated that this maintenance of IOR after a search depends on the presence of the display. For instance, there is evidence that IOR is no longer present after a search is finished if the display is removed once the probe is presented (Müller & von Mühlenen, 2000; Takeda & Yagi, 2000). This finding indicates that IOR is object-based rather than location-based and it also suggests that it is active as long as the visual input is present.

In Höfler, Gilchrist, and Körner (2011) we investigated in three experiments whether and how saccadic IOR supports search when the same display is searched twice for different target letters. In line with the literature on single searches, we observed IOR *during* each of the two consecutive searches (see Fig. 1 for the results of Experiment 1; Höfler et al., 2011): Saccadic responses were longer when a previously inspected item as compared to a non-inspected item was probed while participants were “in the midst” of the first or the second search. However, at the time when the first search was completed, IOR seemed to be no longer active: Saccadic responses to recently inspected items of the previous search took almost the same time as saccadic responses to previously non-inspected items. This suggests that the completion of a search might lead to the reset of IOR at the end of the first search before it is resumed when a further search in the same environment is required. The finding was underpinned by a further experiment in Höfler et al. (2011) in which the participants

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were not allowed to complete the first search. Rather, while they were searching for the first target, search was interrupted by prompting the next target such that they had to switch to the next search immediately. As compared to a condition in which they completed the first search, IOR was active across searches in this interrupted-search condition.

The finding that IOR is no longer active when a search is completed challenges some results from previous research that addressed the involvement of IOR in single searches (see above). In particular, if IOR relies on the presence of the objects in the display after a search is completed (Müller & von Mühlenen, 2000; Takeda & Yagi, 2000), we would expect that IOR is maintained across two consecutive searches in the same display (because the display does neither change nor disappear across the searches) which was not supported by our previous findings. However, whether or not IOR remains active after a search might also depend on the subsequent task. If a search is completed and no further search follows directly (as is the case in most experiments on this topic in the literature; e.g. Klein, 1988), IOR might remain active after the end of the search because it does not have any detrimental effect. However, when a further search in the same environment is required, a "reset" of IOR after the first search might ensure that the upcoming search can be conducted without compromising search efficiency due to the inhibition of previously inspected items.

In the present experiments, we investigated whether IOR persists after the completion of a search and whether it depends on the same display being searched again after completion. To this end, we adhered closely to the paradigm as established by Höfler et al. (2011). In Experiment 1, we had participants repeatedly search the same display twice and probed for IOR both at the beginning of the second search (in order to test again if it is absent across searches) and after the end of the second search (in order to test if it is present once no further search is conducted in the same display). If the occurrence of IOR after a search depends on the subsequent task, we would expect to find IOR after the end of the second search but not after the end of the first search (that is, not "across" two consecutive searches). Furthermore, in Experiment 2 we ran a version of Experiment 1 in which participants had to search a display only once. In this experiment we tested for IOR during and after the end of the search, using a saccadic response and in addition a manual response.

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2 Experiment 1

2.1 Method

2.1.1 Design—In each trial, participants had to search in the same display of 15 letters twice consecutively for two different target letters. The target letter was absent on half of the searches such that targets were equally often present in both searches. During each trial, we presented two probes at two crucial times: The *across probe* was presented 300 ms after the start of the second search (i.e., after the first search was completed); the *post-search probe* was presented 300 ms after participants had completed the second search. There were two probe types: An old probe had either been recently fixated (i.e., within the last four item fixations) in Search 1 (for across probes) or in Search 2 (for post-search probes). A *new probe* appeared at items that had not been fixated during Search 1 (across probe) or during Search 2 (post-search probe). All manipulations were made within subjects. Saccadic latencies to the probe were used as the main dependent variable. Saccadic latency was defined as the time between the onset of the probe and the start of the corresponding saccade to the probe.

2.1.2 Participants—Eight participants (two female) took part in this experiment. All of them were naïve to the goal of the study and received class credit. They were 24.4 years old on average (*SD* = 3.0; range 21 to 29 years). All participants had normal or corrected-to-normal vision (contact lenses) and gave informed consent. The work was approved by the local ethics committee.

2.1.3 Apparatus—An EyeLink 2 eye tracker (SR Research, Ontario, Canada) was used to collect the data. Sampling rate was 500 Hz. Velocity threshold for saccade detection was set to 35°/s and acceleration threshold to 9500°/s^2. Data were collected from the eye which produced the better spatial resolution during the set-up phase (typically better than 0.31°). The search displays were presented on a 21-in. CRT-monitor with a refresh rate of 100 Hz and a resolution of 1152 × 864 pixels. Viewing distance was approximately 63 cm. To minimise head movements participants had to rest their head on a chin rest. Manual responses were collected with a gamepad.

2.1.4 Stimuli—For each trial, 15 upper case letters (Arial font, bold) were sampled randomly from a set of 17 letters of the Roman alphabet (the letters B, C, D, J, N, Q, W, X, and Y were omitted) and presented in the display. The two remaining letters were used as targets in case of target-absent searches. The letters subtended 0.32° and were surrounded by a circle (0.18° thick) to minimise the peripheral vision of the item. The diameter of an item (letter and circle) was 0.9°. The items were placed (with a deviation within ± 0.23° both in horizontal and vertical direction) on the intersections of an imaginary 6 × 6 grid. The size of a grid cell was 3.6°. The stimuli were presented in white on a black background.

2.1.5 Procedure—At the beginning of each trial, participants were instructed to fixate a fixation disc for a drift correction (see Fig. 2). The experimenter started the trial when the fixation was registered. Afterwards, a placeholder display was presented. It was identical to the search display except that each letter was replaced by the hash symbol (#). The placeholder was substituted by the search display after 500 ms. With the search display onset, the first target letter was announced through loudspeakers. Participants had to search for the target letter and to give a manual target present or absent response. After this first manual response the second search started immediately with the announcement of a new target followed by the presentation of the probe 300 ms afterwards. The probe was either chosen from the items which had been fixated within the last one to four item fixations in Search 1 (old probe) or not fixated at all in Search 1 (new probe). The distance between current fixated item and the probed items was held constant with about 10.8°. The participants were instructed to immediately saccade to this probe and continue the search. After the second manual search response was given, the search display remained visible and a sound similar to the sound of target letters was played (“mmh”). However, the sound was task-irrelevant and, more critically, it was easily discriminable from the letters presented as possible targets. Participants were instructed to ignore the sound because no further search would follow after they had completed the second search. 300 ms after the end of the second

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search (i.e. after the participant pressed the response button), a probe was presented again (post-search probe) and participants were instructed to saccade to the probe. The probed item was selected and presented using the same criteria as for the across probe. If a suitable probe could not be selected, the display was cleared and a new trial started.

Participants performed eight practice trials before the first experimental block. In these practice trials, the distinction between a target letter and the control sound after the end of the second search was explained to the participants. Each participant completed eight blocks with 80 trials each. 16 trials in each block were catch trials. In eight of these catch trials, only one probe (across probe or post-search probe) appeared during a trial. In the remaining eight catch trials, no probe appeared at all. The eight blocks were divided into two or three sessions of two to four blocks on different days. One block lasted approximately 20 min. Participants were allowed to have breaks of several minutes between blocks.

2.2 Results and discussion

From a total of 4480 trials, four trials were lost due to technical problems. Overall search error rate was low with 7.4% (SD = 5.2%). Participants missed a target in 5.1% (SD = 6.4%) of the trials in the first search and 2.7% (SD = 2.9) in the second search. The false alarm rate in the first search was 0.4% (SD = 0.2%) and 2.7% (SD = 3.4%) in the second search. Fig. 3 shows mean saccadic latencies (averaged across individual means) separately for each search condition. Saccadic latencies for across probes were 167 ms (SD = 32; old probe) and 168 ms (SD = 43; new probe), and for post probes 198 ms (SD = 69; old probe) and 196 ms (SD = 81; new probe), respectively.

In order to determine whether IOR was active across and after a search, we fitted a generalised linear mixed model. The data were analysed using the lme4 package (version 1.1–21, Bates, Maechler, Bolker, & Walker, 2015) in R (version 3.5.1 R-Core Development Team, 2016). Since our response times followed a gamma distribution, we used this distribution with the link identity function model to analyse the data. Prior to our analysis, we excluded data from one participant as he or she did not saccade to the probe most of the time. Furthermore, we excluded searches in which no probe was presented, saccadic latencies were less than 50 ms, participants did not fixate the probe with the first fixation after probe onset, or in which the probe was chosen randomly. Furthermore, we did not include searches in which the target was absent in the search before the probe was presented, because on most of those trials new probes could not be presented. After these exclusions, we obtained 1790 trials for our analysis.

We treated probe time (across or post search) and probe type (old or new) as fixed effects and saccadic latencies to the probe as dependent variable. We also included the two-way interaction in our model. Furthermore, we treated participant as a random factor. As a t-distribution with a high degree of freedom approaches the z distribution, absolute t values larger than 1.96 can be considered significant at $p < .05$ (Baayen, Davidson, & Bates, 2008). Model output for Experiment 1 is shown in Table 1.

We found a significant effect of probe time. Participants showed longer saccadic latencies after a search than across searches. This suggests that participants needed longer to respond

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to the probe after the search task was completed. The non-significant fixed effect probe type and non-significant interaction suggest that there was no active IOR across or after a search.

The acceptance of the null hypothesis on the basis of missing effects is not possible in traditional frequentist statistics (Wagenmakers, 2007). We therefore conducted an additional Bayes analysis of our data that allowed us to quantify the evidence for the null finding. The Bayes factor (BF) is a ratio that expresses the likelihood of the data under the null hypothesis relative to the likelihood of the data given the alternative hypothesis. For example, $BF_{01} = 2.0$ means that the data are twice as likely under the null hypothesis than under the alternative; taking the inverse, $BF_{10} = 0.5$, indicates that the alternative hypothesis is half as likely as the null hypothesis.

In order to conduct a Bayes analyses, we re-analysed the data of six of our previous experiments with similar paradigms in which we had observed IOR effects (Bauch, Körner, Gilchrist, & Höfler, 2016; Höfler et al., 2011; Höfler, Gilchrist, Ischebeck, & Körner, 2015; Höfler, Gilchrist, & Körner, 2015b) and found effect sizes (Cohen's *d*) which ranged from 0.85 to 2.14 (*Md* = 1.22) if IOR was present. Then we specified a null hypothesis region (Morey & Rouder, 2011) that states that the true effect size is within some range between 0 and 0.2 in case there is no reliable effect. In contrast, as support for the alternative hypothesis, we specified that the true effect size has to be equal to or greater than 0.2. Given the effect sizes for all reliable IOR effects from the reanalysis of our previous experiments we consider this choice of intervals very conservative. We computed the Bayes factor using the BayesFactor package for R (version 0.9.2; http://bayesfactorpcl.r-forge.r-project.org/). We found Bayes factors in favour for the alternative hypothesis of $BF_{10} = 0.21$ for the across probe and $BF_{10} = 0.21$ for the post-search probe. Computing the inverse, we found $BF_{01} = 4.76$ (across probe) and $BF_{01} = 3.42$ (post-search probe), respectively. This means that the data are about 4.8 (across-search probe) and 3.4 (post-search probe) times, respectively, more likely under the null hypothesis than under the alternative hypothesis. Hence, the Bayes factors represent substantial support of the data for the null hypothesis (Jarosz & Wiley, 2014).

Together, these findings suggest that there is no IOR effect after a search is completed. This seems to be the case regardless of whether there is another search following immediately (across probe) or whether the trial ends (post search). There are several arguments on why we could not find IOR after the searches, however. First, it might be possible that IOR was not active during the search in the first place such that IOR was neither “reset” across searches nor “diminished” after the second search as it was never active within the two searches. Although we found repeatedly IOR within two (completed) consecutive searches but not across them (Höfler et al., 2011) we cannot be sure that this was also true in the current experiment. Therefore, in Experiment 2, we also tested for IOR while a search is ongoing. Furthermore, the result that IOR is not active after a search in case no further search follows immediately stands in contrast to previous findings that showed IOR to be present after a search is completed and no search follows (Klein, 1988). One reason for this difference might be that we used saccadic responses to test for the effect of IOR whereas previous experiments mostly used manual responses. As differences between these two measures have been repeatedly observed in paradigms using cueing tasks (Chica, Taylor, Lupiáñez, & Klein, 2010; Hilchey, Dohmen, Crowder, & Klein, 2016; Taylor & Klein, 2000), we wanted to test whether the lack of finding IOR after the end of the second search (where no further search follows) was due to the response mode. For instance, the findings of MacInnes, Krüger, and Hunt (2015) suggested that IOR, when measured with saccadic responses, was rather short-lived (less than 900 ms) as compared to IOR when measured via manual responses. Furthermore, Briand, Larrison, and Sereno (2000) showed that saccadic and manual responses differed in the time course such that IOR was observed earlier for saccadic than for manual responses. Hence, in Experiment 2 we investigated whether there is IOR during and after the end of a single search, and we collected both manual and saccadic responses in order to measure it.

3 Experiment 2

3.1 Method

3.1.1 Participants—Eighteen new participants (11 female) volunteered for this experiment. They were 23.3 years on average (*SD* = 2.8, range from 20 to 29 years) and gave informed consent. The work was approved by the local ethics committee.

3.1.2 Design, stimuli, and procedure—Design, stimuli and procedure were the same as in the previous experiment except that participants had to search the 15-letter display only once. Within a trial, a probe was presented twice: while the search was still ongoing (within-search probe) and immediately after the end of the search (post-search probe). The within-search probe was presented randomly after the fifth to ninth fixation during the search; the post-search probe was presented 300 ms after the participant pressed a response button. Again, the probe was either recently inspected during search (old probe) or not (new probe) in each case. Critically, we measured either saccadic latencies or manual response times to the probe. As in Experiment 1, the participants completed eight blocks with the instruction to saccade to the probe. In further four blocks they were instructed not to saccade to the probe but to press both trigger buttons simultaneously on the game pad as soon as the probe appeared. Each participant completed 12 blocks (four with manual, eight with saccadic response to the probe in counterbalanced order) of 86 trials each in three sessions of four blocks. We again included 18 catch trials per block. Participants were allowed to have short breaks of several minutes between blocks.

3.1.3 Apparatus—We used an Eyelink 1000+ eye tracker (SR Research, Ontario, Canada) to collect the data. Eye movements were recorded monocularly with a sampling rate of 1000 Hz. The settings for saccade detection and the size of the stimuli (in terms of visual angle) were the same as in Experiment 1. The stimuli were presented on a 21 in. monitor with a refresh rate of 85 Hz. Viewing distance was approximately 75 cm.

3.2 Results and discussion

We collected data from 18,576 trials (86 trials × 12 blocks × 18 participants; 12,384 for the saccadic response condition; 6192 for the manual response condition). We lost 152 trials due to technical problems. The false alarm rate in trials with saccadic response was 1.0% (*SD* = 0.8%) and 1.8% (*SD* = 1.9%) in trials with manual response. Participants missed a target in

7.5% (*SD* = 5.4%) in trials with saccadic response and 8.4% (*SD* = 6.4) in trials with manual response. As in Experiment 1, we excluded all trials with technical problems, trials in which either no probe occurred or it was chosen randomly or in which the probe was not fixated immediately with the first fixation after its onset (when a saccadic response was required). In the manual response condition, we only analysed trials in which a button was pressed after probe onset and no eye movement to the probe was made between probe onset and manual response. Furthermore, we excluded saccadic latencies smaller than 50 ms in the saccadic response condition and manual latencies shorter than 100 ms and longer than 1500 ms in the manual response condition. Summed across participants, we analysed 3123 searches (within search) and 3784 searches (post search) for the latency analysis of the saccadic response condition and 3057 searches (within search) and 1956 searches (post search) for the latency analysis of the manual response condition, respectively. For within-search probes, mean saccadic latencies to old probes took 272 ms (*SD* = 37) and 252 ms (*SD* = 33) to new probes; for post-search probes 220 ms (*SD* = 38) and 212 ms (*SD* = 33; see Fig. 4). Manual responses took 720 ms (*SD* = 106) to old probes and 728 ms (*SD* = 99) to new probes within search, and 363 ms (*SD* = 54) to old probes and 359 ms (*SD* = 53) to new probes post search.

As in Experiment 1, we conducted generalised linear mixed models analyses. The distribution of manual response latencies showed a bimodal distribution with longer latencies within search and shorter latencies post search. Therefore, we analysed manual latencies for the probe times (within vs. post probe) separately. For saccadic latencies, we treated probe time and probe type as fixed effects and for manual latencies probe type only. For all models, we included participant as a random effect (see Table 2).

For saccadic latencies, we found a significant fixed effect of probe time with shorter latencies after a search than within a search. The significant fixed effect of probe type with longer latencies for old probes indicates that IOR was present during and after the search. For manual latencies, we found no fixed effect of probe type which suggests that IOR was neither active during nor after the search.

In order to provide more direct evidence for the lack of a probe effect for manual responses, we again performed a Bayes factor analysis with intervals for null and alternative hypotheses as defined for Experiment 1. With regard to the comparison of old vs. new probes, neither the Bayes factor for within search (BF_{10} = 0.22) nor post search probes (BF_{10} = 0.33) provided evidence in favour of the alternative hypothesis. The Bayes factors indicated support for the null hypothesis instead (within search BF_{01} = 4.57, post search BF_{01} = 3.05).

In all cases where IOR was found after a search was completed it was typically measured via manual responses, without concurrently measuring – or preventing – eye movements (e.g., Klein, 1988). It is therefore possible that the manual response to the probed item in these experiments was accompanied by a saccadic eye movement to the probe. This could have increased a possible IOR effect which, in the manual response data alone, was not present. In our analysis of manual responses in Experiment 2 we had excluded any cases where participants made a concurrent saccade. To better compare our data to those reported in the literature, we re-analysed the manual-response data but included all responses to old and

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new probes during and after the search regardless of whether a saccadic response to the probe was made at the same time or not. This led to an inclusion of further 741 within-search probes (i.e., 3798 in total) and 369 post-search probes (2325 trials). Still, the results did not change after including these trials: Manual responses during search were *M* = 717 ms (*SD* = 109) to old probes and *M* = 726 ms (*SD* = 103) to new probes, and, after the end of the search *M* = 379 ms (*SD* = 53) to old and *M* = 369 ms (*SD* = 55) new probes. This again underlines that IOR was present neither during nor after the search when manual responses to a probe were required. However, we cannot rule out the possibility that the presence of IOR was overshadowed or obscured by facilitatory effects (Posner & Cohen, 1984). This is subject to further experimentation.

4 General discussion

We had previously demonstrated that IOR was present during the first of two consecutive searches in the same display but it was absent at the beginning of the second search (Höfler et al., 2011). This suggested that IOR is no longer active after a visual search is completed and appeared to stand in contrast to findings that demonstrated IOR after a search. In the current paper we further investigated under which circumstances IOR is present after the end of a search. In Experiment 1, we investigated whether such a post-search IOR depends on the presence of a further search in the same display. To this end, we had participants search the same display twice. We found no IOR after the end of the first *and* the second search; i.e., regardless of whether or not a subsequent search followed in the same display. In Experiment 2, we tested whether IOR was at all active during the search and whether the (non-) occurrence of IOR after search depended on the type of response (manual vs. saccadic). Here, IOR was observed during and after search for the saccadic response condition. The presence of saccadic IOR during search was expected, the presence after search, however, contradicted the absence of saccadic IOR after search in Experiment 1. In Experiment 2, there was no IOR for the manual response condition. Taken together, our findings suggest that saccadic IOR is present during search, and may remain active after a search is completed and no further search follows. With regard to manual IOR, we did not find evidence that it is active at all during or after a search.

In Experiment 1 we showed that IOR is no longer active across the two searches and after the second search. When participants completed the first search and a new search target was announced, IOR was not observed. This is in line with the findings of Höfler et al. (2011) who, using a similar paradigm, showed that IOR was active during both of two consecutive searches but not across them (see Fig. 1). Höfler et al. (2011) argued that IOR was reset after the first search because in this way search could be, without any bias, guided back to recently inspected items if the target of the second search was among these items. Previous research has indeed indicated that targets of the second search are found faster if they were inspected recently during the first search (Höfler et al., 2014; Körner & Gilchrist, 2007; Körner, Höfler, Ischebeck, & Gilchrist, 2018). This would support the assumption that recently inspected items are no longer inhibited if a further search in the same display is required.

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However, after a search is completed and no further search follows, the picture of whether IOR is still active is not that clear. Although we did not find evidence for saccadic IOR in Experiment 1 after the second search was completed, the findings of Experiment 2 suggest otherwise: saccadic IOR was still present after the end of the search. The absence of IOR in Experiment 1 and its presence in Experiment 2 may be the consequence of increased statistical power in the latter experiment. In Experiment 1, we had used a comparatively small sample with a large number of trials per participant, an approach that is typical and reasonable in vision research (Smith & Little, 2018). Indeed, in earlier experiments (of our own and of others) using this approach, statistical power seemed sufficient to reliably detect IOR when it was present(e.g., Boot et al., 2004; Höfler et al., 2011; Klein, 1988; Klein & MacInnes, 1999). We also used a linear mixed-model analysis to account for within-condition variance. Nonetheless, with twice the sample size of Experiment 1 the statistical power was higher in Experiment 2 which gives greater weight to these results.

There is at least one – highly speculative – interpretation that would reconcile the absence of IOR after a repeated search (as in Experiment 1) with the presence of IOR after a single search (as in Experiment 2). As we have pointed out above, a repeated search task may cause IOR to be turned off at the beginning of a subsequent search so that the search process can be guided back to recently inspected items if the target of the subsequent search is among them. In a task where an observer performs hundreds of such repeated searches it may be economical to have IOR turned off permanently at the end of a search. In contrast, in a single search task any persisting inhibition of recently inspected items would be of no harm because there is no immediate further task to perform. In this situation, the switching off of IOR would simply be unnecessary. Indeed, IOR has been shown to be sensitive to task demands (Dodd, Van der Stigchel, & Hollingworth, 2009), and it seems possible that the completion of a search task has different consequences for IOR depending on the overall task.

In Experiment 2, we additionally measured both manual and saccadic responses as the null finding of Experiment 1 might have been due to the type of response we measured. There is evidence that there is a dissociation between an action-based or motoric IOR and a perceptual IOR at least when a cueing paradigm is used (Hilchey et al., 2016; Hilchey, Klein, & Satel, 2014; Tayler & Klein, 2000): Whereas motoric IOR is considered to be a bias against the re-inspection of previously cued or inspected items when eye movements are allowed (as in Experiment 1), perceptual IOR is considered a slowed processing of information presented at a cued versus uncued location when eye movements are discouraged (Chica et al., 2010). Our findings indeed revealed differences between the response modes with regard to IOR during and after a visual search task. While we replicated previous findings on saccadic IOR during search and found some evidence for saccadic IOR after a search, we could not find any evidence for manual IOR at any stage of the search. The consequence of this latter finding is difficult to interpret, as, at least to our knowledge, IOR during search has so far never been investigated by using manual responses to a probe presented on a previously foveated vs. non-foveated item. Most of the information about whether IOR facilitates search *while* search is ongoing has come from analysing saccadic responses to a probe (e.g. Dodd et al., 2009; Klein & MacInnes, 1999; MacInnes & Klein, 2003). One exception is provided by Thomas and Lleras (2009) in which a manual response to a probe was required while the search was interrupted. In fact, the results showed a facilitation effect at the beginning of the search that reversed to an inhibition effect when participants had more time to inspect the search array.

In another experiment, Thomas et al. (2006) used a virtual-reality environment in which participants were asked to point at a leaf to select it and to press a button to make the fruit visible if it was present. IOR was measured with a “probe” such that one of the leaves flickered. This probed leaf was either at a previously inspected location or it had never been visited before. Participants were faster when responding to probed leaves they had never inspected before compared to inspected leaves, thus indicating IOR during search. However, the task in that study is difficult to compare with the current experiment as the time frames were quite different. That is, Thomas et al. (2006) themselves stated that in their study IOR lasted about 2 s longer than in more traditional paradigms. Furthermore, eye, head, and arm movements were required to complete the search and the probing task. Hence, different response modalities might have driven the effect of IOR. Further research is needed using manual responses to probes presented on previously foveated items in order to confirm our novel results.

5 Conclusion

Taken together, the findings here provide evidence that there is a difference between saccadic and manual IOR in visual search. Whereas saccadic IOR was present during and after a single search (that is, without a further search following immediately) no IOR was observed when manual responses were used as primary measures. If search is repeated in the same display, saccadic IOR may not be present post search. As, to our knowledge, the current experiment is the first that investigates/compares manual and saccadic IOR during and after the completion of a visual search task, these findings might be a starting point for investigating whether IOR in visual search differs with regard to response modality. It is subject to future research to collect more evidence with different paradigms and methods to improve our knowledge about the circumstances under which IOR is observable.

Acknowledgments

This work was supported by the Austrian Science Fund (FWF): P 28546. We thank Paul Pürcher for his help during the preparation of the manuscript. Parts of the results were presented at the 41st European Conference of Visual Perception, August 2018, Trieste, Italy.

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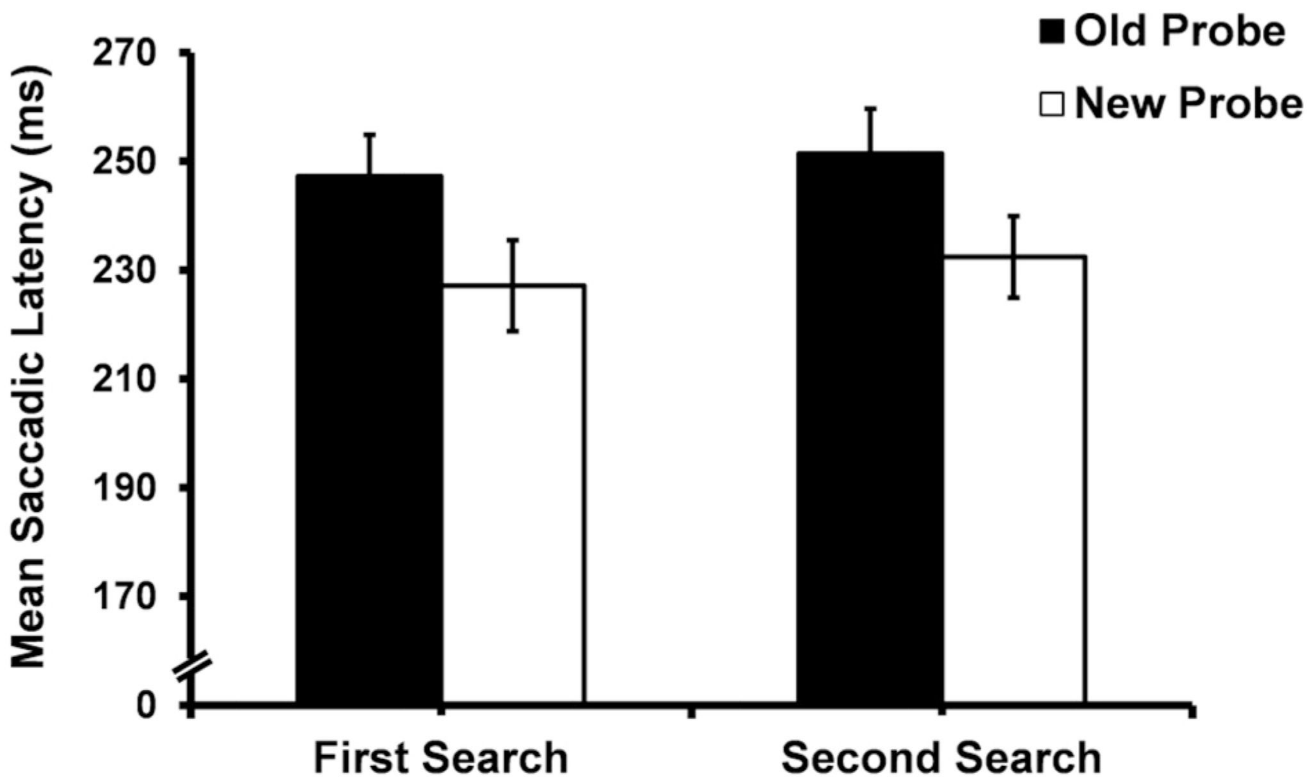

Fig. 1.

Inhibition of return during two consecutive searches. Mean of the individual mean saccadic latencies for old and new probes presented in the first search and in the second search. Data reanalysed from Höfler et al. (2011).

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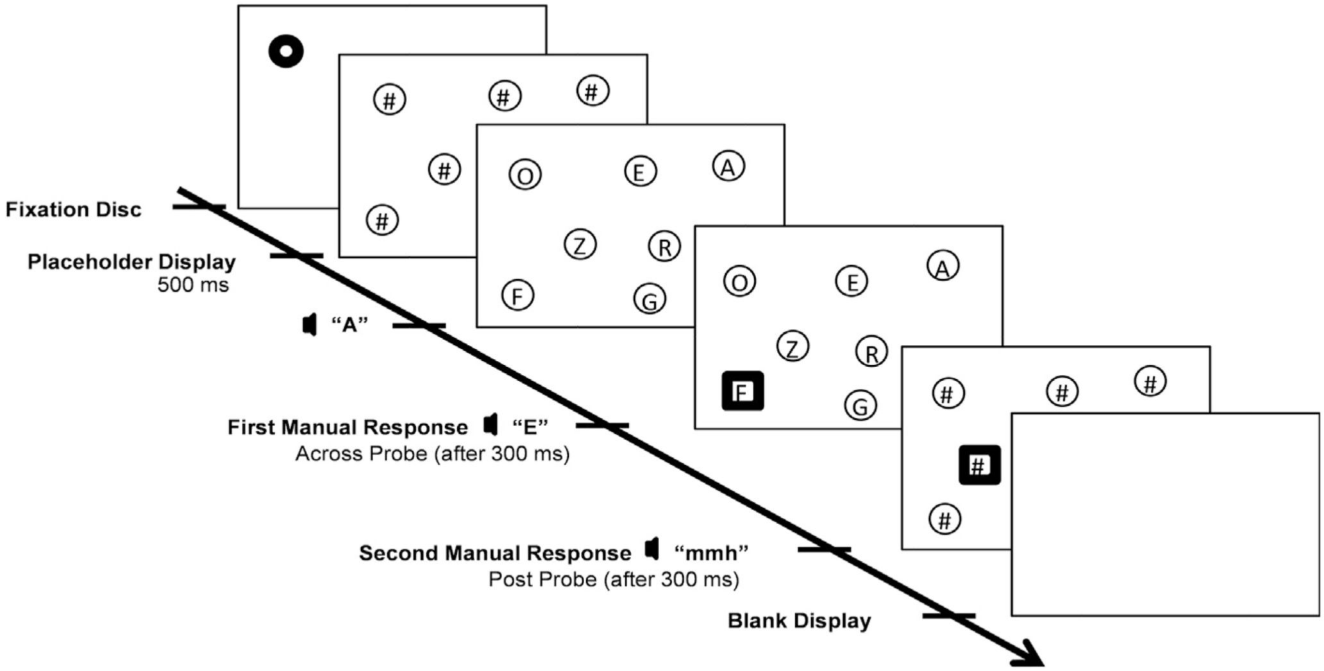

Fig. 2.
Experiment 1. Sequence of events in a trial.

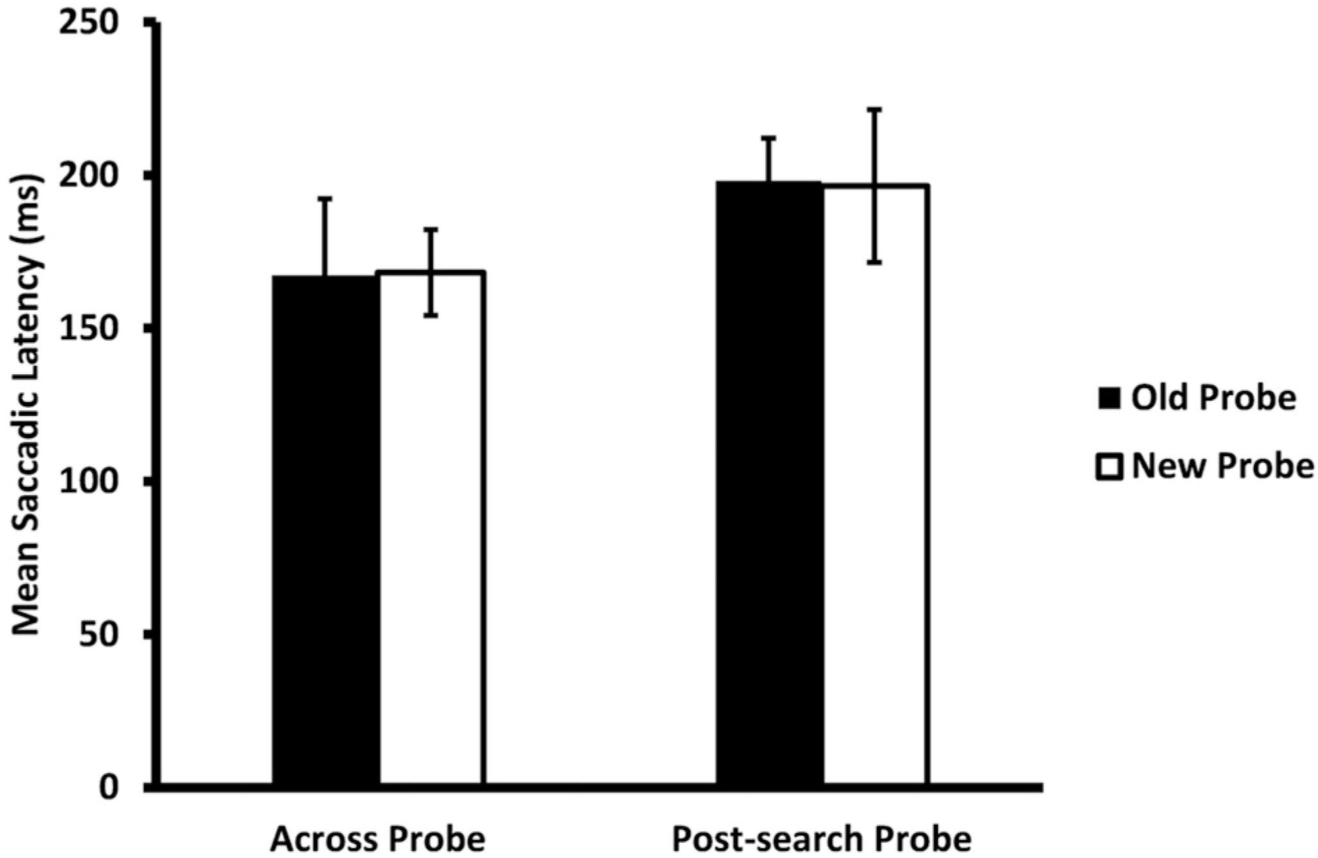

Fig. 3.

Experiment 1. Saccadic latencies to old and new probes across searches (across probe) and after the second search was completed (post-search probe). Error bars represent the 95% confidence intervals (Cousineau, 2005; Morey, 2008).

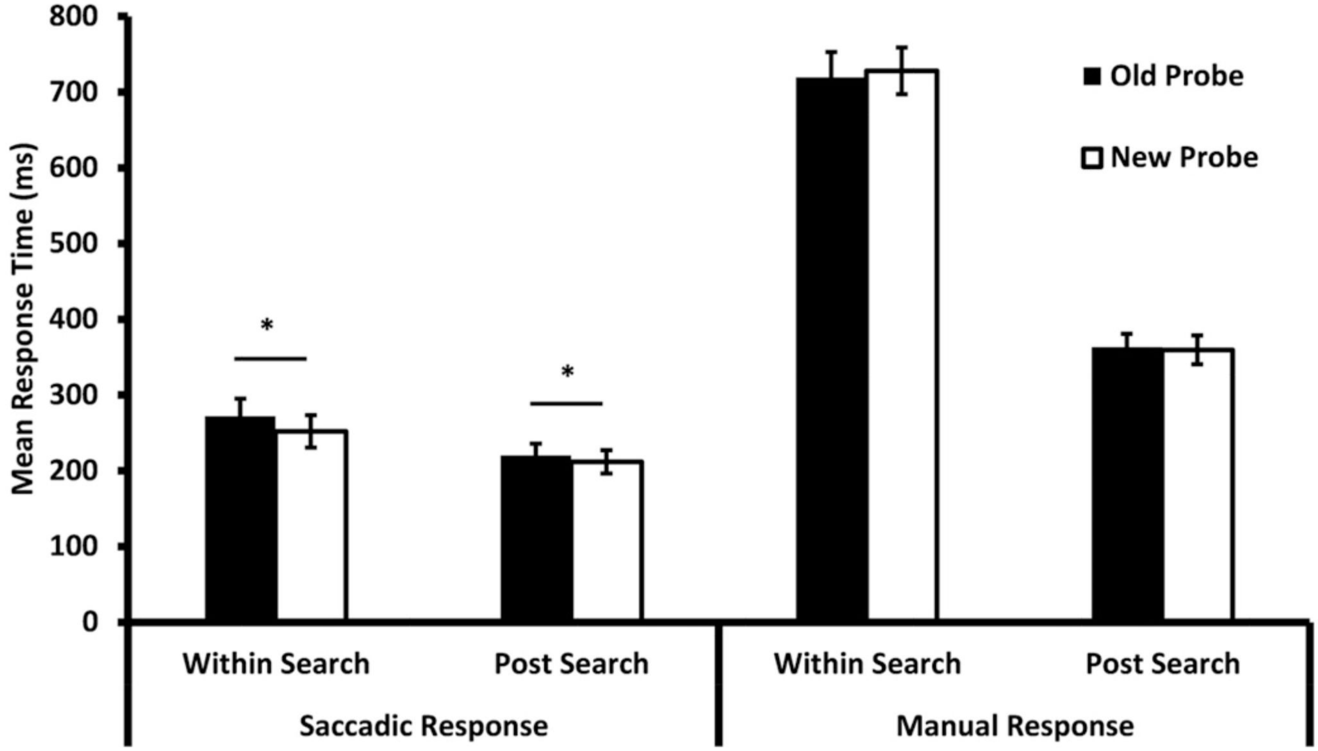

Fig. 4.
Responses for saccadic and manual responses to old and new probes within and post search. Error bars represent the 95% confidence intervals (Cousineau, 2005; Morey, 2008).

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Table 1

Experiment 1. Generalised linear mixed-model analysis for saccadic latencies.

	Estimate	***SE***	***t*-value**
Fixed effects			
Intercept	**179.02**	**13.04**	**13.73**
Probe Time	**16.83**	**3.43**	**4.90**
Probe Type	4.51	3.53	1.28
Probe Time × Probe Type	−0.96	4.81	0.84
Random effects	Variance	*SD*	
Participant (Intercept)	694.71	26.36	

Note. Bold terms represent significant effects.

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Table 2

Experiment 2. Generalised linear mixed-model analysis for saccadic and manual latencies.

	Estimate	*SE*	*t*-value
Saccadic responses			
Fixed effects			
Intercept	**211.55**	**3.83**	**55.22**
Probe Time	**46.39**	**2.63**	**17.66**
Probe Type	**6.55**	**2.26**	**2.90**
Probe Time × Probe Type	5.13	3.82	1.34
Random effects	Variance	*SD*	
Participant (Intercept)	219.52	14.82	
Manual responses within search			
Fixed effects			
Intercept	**724.96**	**12.78**	**56.74**
Probe Type	−7.92	6.72	−1.18
Random effects	Variance	*SD*	
Subject (Intercept)	2473.00	49.73	
Manual responses post search			
Fixed effects			
Intercept	**357.13**	**8.78**	**40.66**
Probe Type	4.88	6.18	0.79
Random effects	Variance	SD	
Subject (Intercept)	1055.99	32.50	

Note. Bold terms represent significant effects.