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RESEARCH NOTE

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# Inhibition of return in saccadic eye movements

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**Abstract** Inhibition of return (IOR) is a phenomenon in which responses generated to targets at previously attended locations are delayed. It has been suggested that IOR affords a mechanism for optimizing the inspection of novel locations and that it is generated by oculomotor reflexes mediated by the superior colliculus. In this investigation, we measured the effects of IOR on the metrics of saccadic eye movements made to novel and previously attended locations. Saccades made to cued target locations, as well as to other targets within the same hemifield, had longer latencies than saccades made towards the novel, uncued hemifield. We further found that the amplitudes of saccades towards the cued hemifield were more hypometric, but only when the amplitude could not be pre-programmed. These results provide evidence that IOR influences spatial, as well as temporal, parameters of saccadic eye movements and suggest that the exogenous orienting of attention, in addition to influencing target detection, also influences oculomotor programming.

**Key words** Attention · Saccades · Inhibition of return · Oculomotor programming · Human

## Introduction

Previous studies have shown that, like delays in re-fixating with saccadic eye movements (Vaughan 1984), exogenous shifts of covert attention can sometimes slow subsequent target detection (Maylor 1985; Maylor and Hockey 1985; Posner and Cohen 1984; Tassinari and Berlucchi 1995) and the initiation of saccadic eye movements (Abrams and Dobkin 1994; Rafal et al. 1994) to the location of a previous event. This effect was dubbed inhibition of return (IOR) (Posner et al. 1985), indicating their initial suggestion that attention is inhibited to return to previously attended locations. IOR has been suggested to provide a mechanism for optimizing the inspection of novel locations (Posner and Cohen 1984) and may be generated by oculomotor reflexes mediated by the superior colliculus (Danziger et al. 1997; Posner et al. 1985; Rafal et al. 1989; Taylor and Klein 1998).

Although there has been a considerable body of research on IOR, the behavioral and neural mechanisms underlying this inhibitory phenomenon are unclear. Two issues remain to be clarified: the source of the effect, and the site of its action. While the evidence cited above implicates midbrain visuomotor structures in generating IOR, some accounts argue that oculomotor activation is necessary and sufficient to activate it (Rafal et al. 1989), while others argue that voluntary inhibition of a reflexive saccade is required (Chelazzi et al. 1995). Similarly some accounts suggest that the site of action of the inhibitory effect is on perceptual processing (Gibson and Egeth 1994; Pratt 1995; Reuter-Lorenz et al. 1996) while others argue that the inhibitory tag acts as a bias against motor responses (Tassinari and Berlucchi 1995; Taylor and Klein 1998).

The current study investigated the site of IOR, that is, what IOR inhibits. To do so, saccadic eye movement latencies were measured to targets appearing at previously cued locations, as well as to targets appearing within and between the cued hemifields. The metrics of the saccades were also measured to determine whether IOR influences spatial as well as temporal parameters. We show here that IOR can also affect the metrics of a subsequent saccade towards a whole hemifield under some circumstances (cf. Berlucchi et al. 1989; Tassinari et al. 1987), suggesting that IOR may have more direct influences on oculomotor processes than has been shown heretofore.

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**Table 1** Mean saccadic amplitudes (in degrees of visual angle) and latencies (ms) for experiment 1. Standard errors are in parentheses

| | Detection task | | Discrimination | |
|---|---|---|---|---|
| | Cued | Uncued | Cued | Uncued |
| Amplitudes | 4.67 (0.11) | 4.57 (0.13) | 5.04 (0.19) | 5.08 (0.18) |
| Latencies | 217.7 (8.7) | 198.4 (7.8) | 283.4 (17.9) | 266.9 (19.2) |

## Experiment 1

To demonstrate the influence of IOR on saccadic eye movements, a spatial cueing paradigm similar to the one introduced by Posner and Cohen (1984) was used. This cueing procedure typically involves an irrelevant peripheral flash that is presented to reflexively summon attention to a given location. Following the flash of light, or cue, subjects are initially faster to detect targets that appear in the same (cued) location compared to a different (uncued) location. This facilitation of detection at the cued location demonstrates that attention was captured or summoned by the flash of light. However, if a delay of approximately one-fourth of a second or more exists between the cue and the subsequent presentation of the target, subjects are slower to detect the target if it appears in the previously cued location. This IOR has been described as an inhibitory tag that favors novelty in sampling the visual scene, but not much is known about how it influences the spatial parameters of visually guided behaviors. This first experiment measured the effects of IOR on saccadic eye movements to previously cued targets in both a detection and discrimination task. The spatial and temporal parameters of the saccadic eye movements were recorded to reveal any influence of IOR on the generation of saccades.

## Materials and methods

Eight adult subjects, recruited from Washington University, participated in each task of experiment 1 after informed consent. All reported having normal or corrected vision. The analog output from an Applied Science Laboratories (Bedford, MA) Eye-Trac 210 eye movement monitor was digitized and recorded at a rate of 1000 Hz. After the experimental session the recorded signal from the eye movement monitor was then filtered and differentiated using a low-pass filter with an 80-Hz cutoff. The resulting velocity profiles were analyzed to determine the point in time when the initiation of a saccade occurred. The initiation of a saccade was defined as the first moment after the presentation of the peripheral target in which (a) the velocity of the eye exceeded 10°/s and (b) it subsequently reached 35°/s or more for at least 10 ms. The amplitude of the saccade was defined as the total distance traveled during the period in which the eye movement velocity was greater than 35°/s. The eye movement monitor was calibrated at the beginning of each session and the calibration was checked at the beginning of each trial. The saccadic latency data appeared previously (Pratt 1995).

The apparatus, stimuli, and procedures are described in more detail elsewhere (Pratt 1995). Briefly, subjects were instructed to move their eyes to a target shape, either a square or a diamond measuring 0.5° that was presented 5° in eccentricity to the left or right, as soon as it appeared. Prior to the onset of the target shape, an asterisk serving as the cue appeared either in the left or right visual field, which subjects were instructed to ignore. There was always only one shape presented in the detection task and both a square and a diamond in the discrimination task. The cue-to-target stimulus onset asynchrony (SOA) was 960 ms in this experiment. Subjects were instructed as to what the target shape would be prior to the start of each session and to move their eyes as quickly as possible to the target shape.

## Results and discussion

In this first experiment, we examined how IOR influences saccadic eye movements in both a detection as well as a shape discrimination task. Table 1 contains the results of this initial experiment. The results demonstrate delayed saccadic latencies for detecting targets appearing in previously cued locations (218 ms) when compared with targets appearing in uncued target locations (198 ms; $t(7)=7.42$, $P<0.001$). Similarly, saccadic latencies were delayed to target locations when discriminating between two shapes at the previously cued location (283 vs 267; $t(7)=2.44$, $P<0.05$). No differences between cued and uncued locations were found in both tasks, however, when saccadic amplitudes were measured ($P>0.20$ for both).

We used both a detection and a discrimination task in this experiment because it was expected that we might find differential effects on saccadic amplitudes in one task but not in the other. Previous studies have demonstrated that the magnitude and presence of IOR in fact tends to differ upon whether a detection or a discrimination task is used (Lupianez et al. 1997; Tanaka and Shimojo 1996). That no differences between the two tasks were found in any of the measures may be due to the fact that the stimulus parameters and procedures that were employed made the IOR effect very similar across tasks: a long (960 ms) cue-to-target SOA (cf. Lupianez et al. 1997) and a directional or global localization response (cf. Tanaka and Shimojo 1996). Since the effects of IOR on saccadic amplitudes and latencies were the same in both the detection and discrimination task, it may be that task variables other than detection vs discrimination are important in revealing the effects of IOR on saccade metrics.

It has been shown for both hand (Rosenbaum 1980) and saccadic eye movements (Abrams and Jonides 1988) that it is possible to pre-program the amplitude of a movement when the required amplitude is known, even in the absence of information on the required direction of movement. Since in experiment 1 the amplitude of the saccade was always 5°, it is possible that participants could have pre-programmed the saccadic amplitudes prior to the onset of the target. This amplitude pre-programming could have occurred independently of the direction in which the eyes had to move and may not have allowed any spatial biases in the eye movements to be detected.

## Experiment 2

To further examine the influences of IOR on spatial parameters of saccadic eye movements, another experiment was conducted which obviated the possibility of participants pre-programming the saccadic amplitudes. Four target locations, two to the left and two to the right of fixation, were used. If the lack of a spatial bias in the first experiment was due to the use of a constant amplitude of target distance, which allowed subjects to program the amplitude of the saccade prior to the onset of the target, then a spatial bias could be revealed in this second experiment. The current experiment also allowed for measurements of within and between hemifield effects. In addition to expecting a spatial bias due to IOR, we further expected to find a whole hemifield influence of IOR on saccadic latencies, similar to those reported with simple manual detection latencies (Berlucchi et al. 1989; Tassinari et al. 1987).

## Materials and methods

After informed consent, eight subjects recruited from the University of California participated in experiment 2 and reported having normal or corrected vision at the time of testing. In this experiment, five green light-emitting diodes (LEDs) that were 0.4° were used: a central fixation LED and two LEDs that were 5° and 10° to both the left and right. The center LED was illuminated throughout the experiment and was used as the fixation point when eye movements were not being made. The LEDs were controlled through one of two parallel ports of a 486 IBM compatible computer.

Eye position was monitored using an Applied Science Laboratories (Bedford, MA) Eye-Trac 210 that was connected to the other parallel port of the computer. The digital output from the eye movement monitor was sampled at a rate of 1000 Hz and was recorded by the computer after each trial. After the experimental session, the eye movement data were filtered with a 200-Hz low-pass filter. Saccadic eye movements were identified and defined in this experiment as the point at which the velocity of the eye movement exceeded 50°/s. Similar to the previous experiment, the amplitude of the saccade was calculated by measuring the total distance traversed by the eye from the point at which the eye movement velocity exceeded 50°/s to the point when the eye movement velocity dropped below 50°/s.

A 500-Hz tone was presented for 100 ms to inform the subject that the trial was beginning. Following a 2500-ms fixation interval, one of the four outer LEDs was first illuminated for 75 ms to serve as a cue. Any of the four outer LEDs could be flashed with equal probability. A cue-to-target SOA of 750 ms elapsed and a target was then presented by illuminating one of the four outer LEDs for 75 ms. The target was also any one of the four LEDs with equal probability and therefore was in the same location on 25% of the trials. The subjects were instructed to make an eye movement to the location of the second flash as fast and accurately as possible.[1]

## Results and discussion

A two-way ANOVA was conducted on the saccadic latencies with cue and distance of target serving as the two within-subject factors. The factor of cue contained four levels (cued, within hemifield, between hemifield near cue, and between hemifield far cue), whereas the factor of target distance contained two levels (near target and far target). Analysis of saccadic latencies (see Fig. 1a) revealed a main effect of cue due to the slowest eye movements for cued targets (317 ms), the next slowest for uncued targets within the same hemifield (296 ms) and the fastest latencies for uncued, between hemifield targets (266 and 273 ms for the near- and far-between hemifield conditions, respectively; $F_{(3,21)}=20.81$, $P<0.001$ for the main effect and $P$s<0.01 for the separate comparisons). These results are consistent with previous reports demonstrating a whole hemifield IOR for manual key press responses (Berlucchi et al. 1989; Tassinari et al. 1987), and extend these findings by showing that the whole hemifield IOR is also manifest with saccadic latencies. There was also a main effect of target distance,

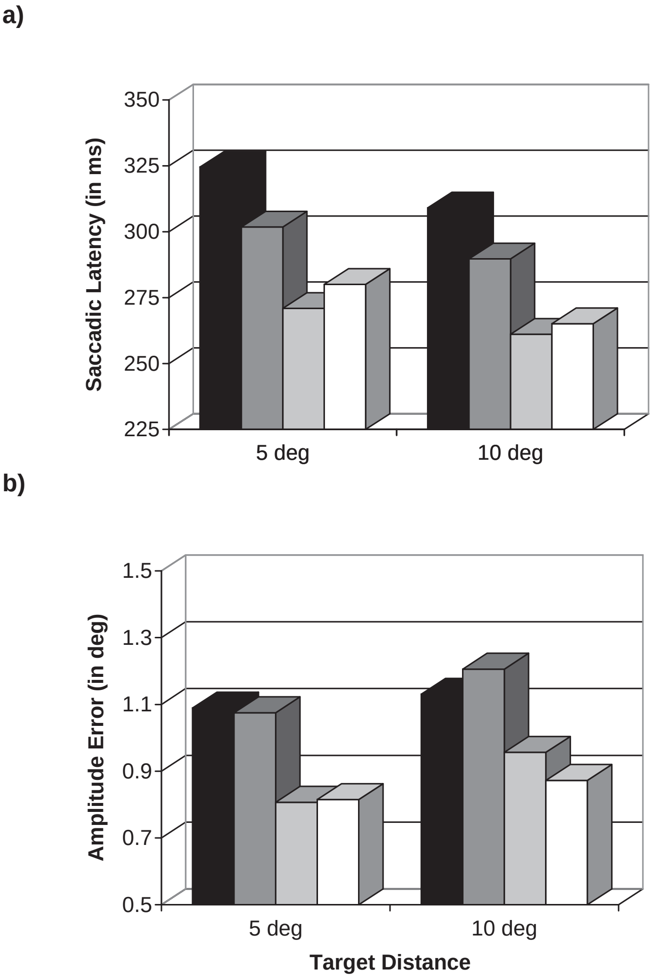

**Fig. 1** Saccadic latencies **(a)** and amplitudes **(b)** for the different cue-target conditions in the four-target location experiment

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[1] Since any difference in the results between this second experiment and the previous one could simply be due to methodological differences, we replicated the previous experiment with the same stimuli and procedures used in this experiment. Only two target LEDs were used in this control experiment and were placed 5° to the left and right of a central fixation LED. The timing and procedures were otherwise identical to this second experiment. The results were similar to those obtained in experiment 1: saccadic latencies were slower to previously cued targets (cued RT of 352 vs uncued RT 321; $t(7)=2.38$, $P<0.05$), but no differences in saccadic amplitude were obtained ($P>0.15$).

with saccadic latencies being longer for targets closer to fixation (294 ms) than targets in the far condition (281 ms; $F_{(1,7)}=6.20$, $P<0.05$). The cue by target distance interaction, however, was not significant ($F<1$). In contrast with a previous study demonstrating the lack of IOR for lateral targets following a medial cue (O'Donnell and Pratt 1996), the present results did reveal an IOR for this condition (302 ms for within hemifield, lateral targets vs 275 ms for between hemifield, lateral targets; $F_{(1,7)}=8.34$, $P<0.025$).

Analysis of saccadic amplitudes (see Fig. 1b) was performed with the same two-way ANOVA as with the saccadic latencies. This analysis revealed a main effect of cue demonstrating that IOR had an influence on saccade metrics in this experiment ($F_{(3,21)}=3.98$, $P<0.025$). Saccades made to targets in the hemifield opposite to the cue (6.62° and 6.66° for the near- and far-between hemifield conditions, respectively) were less hypometric than saccades made to targets at cued locations (6.39°) and to targets at uncued locations within the same hemifield (6.36°; $P<0.05$ for both comparisons). The main effect of target distance was also significant, simply reflecting the increased amplitudes of saccades for the far target condition ($F_{(1,7)}=1647.67$, $P<0.001$). The cue by target distance interaction was not significant ($F<1$). It is interesting to note that this hypometria occurred even though the target locations were demarcated by the LEDs and were always visible. Upon inspection of the eye movement traces for each trial, it was apparent that subjects frequently made corrective saccades to adjust for the hypometria and that postsaccadic drifts were also very frequent.

## General discussion

To summarize, IOR affected the amplitudes of saccades as well as the latencies, but the effect on amplitudes only occurs when the saccadic amplitude cannot be pre-programmed. When a constant target distance was used, participants were able to pre-program the amplitude of the saccade irrespective of the direction of the eye movement and no spatial biases were present. When four target locations with different directions and eccentricities were used, however, spatial biases in the saccadic eye movements were detectable. Subjects had a tendency to not move their eyes as far when moving towards an inhibited direction as compared to eye movements made towards an uninhibited direction.

The IOR to previously cued locations, as well as to a whole hemifield, in this study replicates a number of studies demonstrating that the vertical meridian delimits the extent of the inhibitory effect (Berlucchi et al. 1989; Pratt et al. 1998; but see Pratt et al. 1999; Schmidt 1996; Tassinari et al. 1987, 1989, 1994; Tassinari and Berlucchi 1993; Tassinari and Campara 1996). We further found here that a lateral target following a medial cue was also subject to IOR, contrary to a recent study where no IOR for distant targets was obtained when a cue was closer to fixation (O'Donnell and Pratt 1996). It is presently unclear why the study by O'Donnell and Pratt did not reveal a whole hemifield effect when the cue was medial to the target. It may be that differences in the stimuli (CRT vs LED), as well as methodological and procedural differences, may not have been sensitive enough to detect the whole hemifield effect. What is clear, however, is that the original explanation proposed by O'Donnell and Pratt that IOR only occurs along the path of visual attention needs to be abandoned. This is especially the case given the recent findings of IOR within other sensory modalities, as well as between sensory modalities (Schmidt 1996; Spence and Driver 1998a, 1998b; Tassinari and Campara 1996).

Although the spatial biases against reorienting shown in this investigation provide some evidence consistent with the premotor theory of attention (Corbetta et al. 1998; Kustov and Robinson 1996; Rizzolatti et al. 1987; Sheliga et al. 1995), it is presently unclear what the exact relations are. It could be that these delays and spatial biases observed here are simply secondary to the effects of attention on visual detection. However, other investigations measuring the trajectories and latencies of saccadic eye movements under conditions of cued attention (Kustov and Robinson 1996; Sheliga et al. 1995; Walker et al. 1995) suggest that the oculomotor system is directly involved. Thus, the hypometria reported here may also likely stem directly from effects generated within the oculomotor system. While there is evidence that generation of IOR depends upon the colliculus, the site of its effects involves cortical structures (Tipper et al. 1997); and the current observations are consistent with recent physiological evidence that these effects are implemented via cortical influences back on the superior colliculus (Dorris et al. 1998).

The results reported here demonstrate that IOR influences the programming of saccadic eye movements, and show the reciprocal relationship with previous findings demonstrating that programming saccadic eye movements can generate IOR (Rafal et al. 1989; Schmidt 1996). They further suggest that a large proportion of the eye movements we make in everyday life can be misguided had attention been previously allocated to the target of the saccade. Furthermore, the findings reported here also shed light on the mechanisms through which efficient inspection of novel locations may occur. Spatial and temporal biases against reorienting attention to already inspected locations are likely to maximize the efficiency of visual search.

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