Neuroscience Letters 578 (2014) 128–132

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

The spatial distribution of inhibition of return revisited: No difference found between manual and saccadic responses

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HIGHLIGHTS

- Inhibition of return (IOR) is not restricted to previously attended locations.
- We examine the spatial distribution of IOR with manual and saccadic responses.
- The spatial distribution of IOR cannot be differentiated on the basis of response.
- The spatial distribution of IOR is skewed to more eccentric visual space.

ARTICLE INFO

Article history:
Received 6 April 2014
Received in revised form 20 May 2014
Accepted 13 June 2014
Available online 1 July 2014

Keywords:
Inhibition of return
Saccade
Spatial attention

ABSTRACT

Inhibition of return (IOR) commonly refers to the effect of prolonged response times to targets at previously attended locations. It is a well-documented fact that IOR is not restricted to previously attended locations, but rather has a spatial gradient. Based on a myriad of manual/saccadic dissociations, many researchers now believe that there are at least two forms of IOR completely dissociable on the basis of response type. The present study evaluated whether these two forms of IOR are encoded in similar representations of space. Across a range of conditions, there was little indication that the two forms could be differentiated on the basis of their spatial distributions. Furthermore, the present study also found that the gradient of IOR was steepest for cues appearing nearest fixation.

1. Introduction

Response times (RTs) are slowest toward the location of a transient, spatially uninformative visual signal (a cue) when the interval between the cue and response target exceeds about 200 ms (see [1], for a review). This phenomenon was popularized by Posner and Cohen [2–4] in the spatial cueing paradigm [5] and was later named *inhibition of return* (IOR) [6]. In the seminal demonstration, a visual target appearing in peripheral vision and requiring a speeded response was preceded by an abrupt, spatially uninformative visual onset cue. Initially, RTs to targets appearing at the cued location were fastest. This robust finding is usually attributed to the covert orienting of attention toward the cue [5]. This short-lasting facilitatory effect of attentional orienting gives way to enduring IOR (lasting up to 3 s, see [7] for a graphical meta-analysis). Posner and Cohen suggested that IOR might have been evolved to maximize the sampling of visual information [3]. Posner and colleagues later demonstrated that the mechanisms underlying IOR bias responses against previously inspected locations [6]. Experimental work by Klein and colleagues [8–10] extended this functional explanation of IOR to foraging, demonstrating that IOR facilitates visual search by discouraging reinspections in serial search and complex visual search tasks (for a review, see [11]).

IOR is not restricted to the cued location, but rather has a spatial gradient [12–22]. For instance, in Bennett and Pratt [12], an onset cue at the center of one quadrant of the visual field was followed by a simple manual response target, which could appear at one of 441 locations equally distributed in a $21^\circ \times 21^\circ$ region. The slowest target detection response was observed at the cued location and this effect spread beyond the cued location – decreasing as a function of cue-target distance – but nevertheless spreading to the hemi-field opposite the cue. When multiple transient onset cues are

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http://dx.doi.org/10.1016/j.neulet.2014.06.050
0304-3940/

displayed simultaneously, similar gradients extend outward from the center of gravity – or geometric midpoint – of the cueing arrays [15,18].

Although many investigations (see above) have examined the spatiotemporal dynamics of IOR as a function of cue-target distance, only one investigation [15] has studied whether gradients of IOR are distinguishable on the basis of response type. The paucity of research on this matter is surprising given that experimental work has converged on the notion that the causes and effects of IOR are completely dissociable on the basis of whether the spatial cueing paradigms entail oculomotor and/or keypress responses [23–31], see [32] for a review. Whether IOR is output- (i.e., motoric/decision) or input- (i.e., perception/attention) based depends on whether the oculomotor circuitry responsible for reflexively generated saccades is quiescent or active in the spatial cueing paradigm [25,31–34]. Input-based IOR is generated when the reflexive oculomotor system is quiescent, as in when reflexive saccadic eye movements are expressly forbidden, whereas output-based IOR is generated when the oculomotor system is actively engaged [31,32], as in when reflexive saccadic eye movements are permitted or required to cued locations. In expression, output-based IOR effects are best characterized as speed accuracy tradeoffs whereas input-based IOR effects are best characterized as genuine reductions in performance at the cued location [33,35,36]. The single study (as aforementioned) that has contrasted the spatiotemporal dynamics of input- and output-based forms of IOR as a function of cue-target distance demonstrated striking similarities between them [15]. This observation gives rise to the possibility that both input- and output-based forms of IOR are encoded in the same representation of space. This attribution, however, is made complicated by the high frequency of erroneous saccadic eye movements in the experiment in which manual, not saccadic, responses were required [18]. Indeed, in this experiment, eye movements were made on ~30% of the experimental trials and on ~45% of the "catch" trials on which no response was required. Moreover, observers were not given any explicit feedback in the event of an erroneous oculomotor response. The absence of feedback forbidding oculomotor responding is particularly problematic given that Hilchey et al. have recently demonstrated that IOR is output-based in covert spatial orienting paradigms unless oculomotor responding is expressly discouraged via immediate visual feedback [33]. We worry that the combination of a high rate of oculomotor responding and the absence of explicit feedback warning observers to refrain from reflexively shifting their gaze in Klein, Christie and Morris [18] may have allowed for the output-based form of IOR. Their pattern of results thus may have emerged *not* because input- and output-based forms are encoded in the same representation of space but rather because output-based IOR was probed in both experiments.

In the present investigation, we evaluate spatial gradients of input- and output-based IOR by requiring either manual or saccadic localization responses to visual targets appearing 400 ms after the onset of visual cues. Importantly, immediate visual feedback warning observers to refrain from making saccadic eye movements was delivered at any point time in which an erroneous saccade was detected. In addition to administering variations on the spatial cueing paradigm known to elicit either output- and input-based forms of IOR, our experimental methods were based off of Dorris et al. [17] (see Section 2 for details) and distinct from those in Klein, Christie, and Morris [18] and Christie, Hilchey and Klein [15] in which "center of gravity" effects – the result of multiple simultaneous cues – were of principal interest. We contrast the gradients between input- and output-based forms of IOR under different conditions to ensure that any similarities between them – if observed – are robust across experimental conditions.

2. Method

The research protocol reported here was approved by the Institutional Review Board of Center for Cognition and Brain Disorders at Hangzhou Normal University and all participants gave written informed consent.

2.1. Participants

Eleven graduate students and one faculty member (7 female, 5 male) participated in this experiment in exchange for monetary compensation (40 Yuan/h). They were right-handed, naive to the purpose of the present experiment, and reported normal or corrected-to-normal visual acuity. The mean age was 25.4 (*SD* = 2.7) years.

2.2. Apparatus and stimuli

Participants were tested in a sound-proof, dimly lit laboratory. Visual stimuli were presented on a 21-inch CRT monitor, controlled by a Windows 7 PC (32-bit), equipped with an Intel Core i5-3470 processor (3.2 GHz). The viewing distance was held constant at about 71 cm by using a chin-rest. Stimulus presentation and response registration were controlled by custom software written in Python. A video-based eye tracker (Eyelink® 1000), with a spatial resolution of 0.2° visual angle or better, was used to monitor the participant's gaze direction at a sampling rate of 500 Hz.

The cue was a white empty square (216.8 cd/m^2) measuring $1^\circ \times 1^\circ$ visual angle and the target was a white filled disk (216.8 cd/m^2) with a diameter of 1° visual angle. All stimuli were presented against a black background (6.08 cd/m^2). The target was always presented on the horizontal meridian, 8° left or right to the center of the display. To evaluate the spatial gradient of input- and output-based forms of IOR, we administered variations on two "stimulus-saccade" conditions (the "direction" and "eccentricity" series) from Dorris, Taylor, Klein and Munoz's investigation [17], except that we (1) made some qualitative changes to the visual stimuli and stimulus presentation procedures (e.g., we removed the gap effect because it is known to interact with output- but not input-based IOR [26]), and (2) added corresponding manual response conditions expressly forbidding oculomotor responding but that were, importantly, otherwise identical to the saccade conditions. In the "direction series", the cue appeared on a virtual circle with a radius of 8° whereas in the "eccentricity series" the cue appeared on the horizontal meridian. The cue-target distances were multiples of 22.5° (polar angle) or 2° (visual angle) for the direction and eccentricity series, respectively. Those two series were randomly intermixed within blocks of trial such that on any given trial the cue could appear at any one of 26 locations (see Fig. 1).

2.3. Procedure and design

Self-paced drift check was performed at the beginning of each trial, then a white fixation cross ($1^\circ \times 1^\circ$) appeared at the center of the display and remained visible for the entire trial. After an interval of 1000 ms, the cue appeared randomly at one of 26 possible locations. Participants were told that the cue was spatially uninformative and that it should be ignored. The cue was displayed for 100 ms and the target appeared 300 ms after cue offset (i.e., the cue target onset asynchrony was 400 ms). To minimize anticipatory responses, targets were not presented on 10% of the trials ("catch" trials). When presented, the target appeared for 1500 ms or until the participant made a response. In the saccadic response condition, participants were instructed to make speeded saccadic responses toward the target. In the manual response condition, participants were instructed to make speeded 'Z' (left hand) or '/' (right hand)