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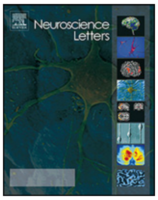

Inhibition of return at different eccentricities in the visual field share the same temporal window

Yan Bao[a,b,e,*], Zhiyuan Wang[a,c], Wei Liang[a], Yi Wang[a], Ernst Pöppel[a,d,e], Hui Li[a,d]

[a] Department of Psychology, Peking University, 5 Yiheyuan Road, Beijing 100871, PR China
[b] Key Laboratory of Machine Perception (Ministry of Education), Peking University, 5 Yiheyuan Road, Beijing 100871, PR China
[c] School of Physics, Peking University, 5 Yiheyuan Road, Beijing 100871, PR China
[d] Institute of Medical Psychology, Ludwig Maximilian University Munich, Goethestr. 31, 80336 Munich, Germany
[e] Human Science Center, Ludwig Maximilian University Munich, Goethestr. 31, 80336 Munich, Germany

HIGHLIGHTS

- IOR magnitude was larger at 21° relative to 7° eccentricity in the visual field.
- IOR at both 7° and 21° eccentricities is characterized by a passive decay over time.
- IOR at both 7° and 21° eccentricities disappears at approximately the same time of 3 s.
- IOR in the visual field is controlled by a common temporal mechanism.

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ABSTRACT

Neurobiological and psychophysical evidence indicates a functional subdivision of the human visual field with a border at approximately 10–15° eccentricity. Recent support for this inhomogeneity comes from an attention study on inhibition of return (IOR), which shows a much stronger IOR effect in the periphery relative to the perifoveal visual field (Bao & Pöppel [1]). Is this inhomogeneity of the visual field also reflected in the temporal dynamics of IOR? To answer this question, we examined when IOR effects disappear at the two functional regions of the visual field. Consistent with previous observations, IOR is much stronger in the periphery relative to the perifoveal visual field, but the two decay functions reach threshold at approximately the same time. This observation suggests a common temporal control window for IOR in both perifoveal and peripheral visual fields.

1. Introduction

Visual attention can be captured by the sudden onset of a peripheral cue, leading to a biphasic processing of a subsequent target appearing at the same location. Facilitation of responding is usually observed when the target immediately follows the cue. However, when the cue-target interval becomes longer, a delayed responding to targets appearing at the cued location relative to the uncued locations will be observed. This latter effect is called “Inhibition of Return” (IOR) and has been generally interpreted as an attentional bias toward novel locations against the previously inspected ones [9,20,21]. This phenomenon has been intensely investigated with respect to its various characteristics and potentially underlying mechanisms [5–8,22,23]. However, one aspect related to the spatial distribution of IOR, i.e. whether IOR is homogeneously distributed throughout the visual field, has not been addressed until an eccentricity effect of IOR was recently described [1].

Neurobiological and psychophysical evidence indicates a functional subdivision of the human visual field with a border at approximately 10–15° eccentricity along the horizontal and vertical meridian. The spatial distribution of light-difference thresholds shows a higher sensitivity for the central and perifoveal visual field which is surrounded by a plateau of constant sensitivity in the peripheral areas [19]. In a study with patients who had suffered injuries of the central visual pathways but leaving some perifoveal and peripheral vision intact, it was found that critical flicker fusion was reduced in the perifoveal region but not beyond [18]. A functional dissociation was also observed in studies of residual vision

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[*] Corresponding author at: Department of Psychology, Peking University, 5 Yiheyuan Road, Beijing 100871, PR China. Tel.: +86 10 62753200;
fax: +86 10 62761081.
E-mail address: baoyan@pku.edu.cn (Y. Bao).

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or “blindsight” [26]. All these studies suggest that the neuronal processing modes for stimuli appearing at perifoveal and peripheral regions of the visual field are qualitatively different.

Motivated by these observations, Bao and Pöppel [1] further asked whether attentional control in the visual field might also underlie a functional dissociation, i.e., showing different processing mechanisms for stimuli appearing in the perifoveal and peripheral regions of the visual field. Since IOR can be seen as an attentional bias in sampling locations in the visual field, it provides a useful and valid measurement for evaluating attentional control in the visual field. By systematically manipulating the stimulus eccentricities of the cues and targets from 5° to 30°, an eccentricity effect of IOR, i.e., a stronger IOR in the periphery relative to the perifoveal visual field, was also demonstrated. This observation suggests that attentional control in the visual field cannot be considered as a homogenous phenomenon, but is characterized by a spatial dissociation. Is this eccentricity effect, however, really a robust phenomenon that can be consistently observed when different stimulus eccentricities from the two functional regions are compared? Will this effect possibly disappear after subjects receive extensive practice during the task? A further study addressed these questions and demonstrated that the eccentricity effect of IOR is a stable phenomenon, i.e., it can be observed when different stimulus eccentricities are compared, and the effect is resistant to subjects’ practice [2]. Being convinced of the robustness of the eccentricity effect, we further asked whether the apparent spatial inhomogeneity of the visual field is also reflected in the temporal dynamics of IOR at different eccentricities, or whether attentional control in the time domain is independent of these spatial factors.

2. Methods

In order to examine the temporal dynamics of IOR in the two functional regions of the visual field, we selected two stimulus eccentricities (7° and 21°), and manipulated the cue-target SOAs (the time interval between the onset of the cue and the onset of the target) in a systematic way. To capture when IOR effects start to disappear, we tested a relatively longer SOA range from 500 ms to 4500 ms. We expect that such a long SOA range is sufficient to capture the offsets of IOR in both regions of the visual field.

Twenty-five students (13 males) aged from 18 to 24 years (mean age = 21.36 years, SD = 1.77 years) from Peking University participated in the experiment for payment. All of them reported normal or corrected-to-normal vision and were naïve to the purpose of the study. The stimuli were white figures on a black background, consisting of a fixation cross at the center, five outline boxes (subtending 1.5°) serving as cues, and a solid dot (0.8°) serving as target. The outline boxes were only presented during the cueing process and did not appear as place holders at other times. The target was preceded by a peripheral cue, which appeared either left or right to the fixation at the same stimulus eccentricity of the target. Participants were asked to respond to the target by pressing the space bar of the keyboard with their dominant hand.

The experiment took place in a dimly illuminated room. Subjects were seated 45 cm from the computer with their heads rested on a chin rest. The center of the screen was set at the subjects’ eye level. A detection task with a typical double-cue IOR paradigm (see Fig. 1) was presented on the computer screen. Each trial started with a fixation cross at the center and remained visible throughout the trial. Following the onset of the fixation cross for 1000 ms, one of the boxes appeared randomly at either 7° or 21° eccentricities to the left or right of the fixation for 100 ms. After an interval of 70 ms, a central cue (same box) appeared at the fixation location for 100 ms. Following a varied interval of 230/1230/2230/3230/4230 ms, a target appeared randomly at either the peripherally cued location or the uncued opposite symmetric location with the same stimulus eccentricity as the cue. The target remained on the screen until the spacebar was pressed. An inter-trial interval of 1000 ms blank screen was inserted before the next trial started. Participants were informed that the peripheral cues did not predict where the target would occur, and they were required to keep their fixation at the cross throughout each trial and detect the targets as quickly and as accurately as possible. On catch trials where there was no target following the cues, participants were asked to withhold their responses, and catch trial ended after 2500 ms of the offset of the central cue. If participants pressed the space bar during catch trials, an error signal (500 Hz tone) was presented for 100 ms. Eye movements of the participants were not monitored in this study since previous studies have shown that subjects only make very few fixation errors [22] and that the pattern of results does not change when eye movements are monitored [e.g., 23]. However, the experimenter did check during the practice session whether the participants can fix their gaze appropriately on the central cross during each trial, and all of them seemed to be able to follow our fixation requirement very well.

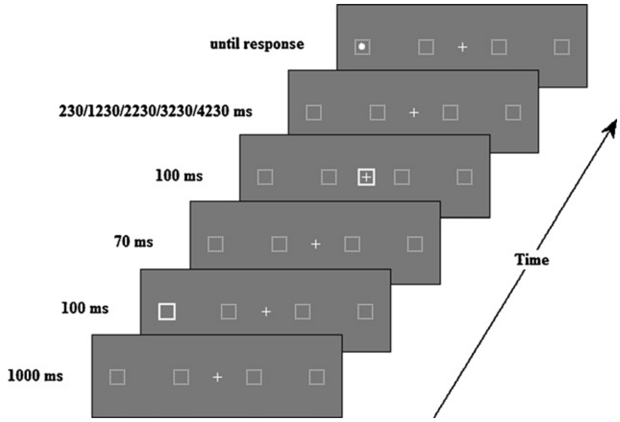

Fig. 1. Sample trial sequence of a typical double-cue IOR paradigm (for details see text).

After a practice block of 48 trials, all participants started the main test, which included 600 target trials and 120 catch trials. All trials were randomized completely and arranged into 15 blocks with 48 trials in each. Trial types were balanced among two stimulus eccentricities (7°/21°), five cue-target SOAs (500/1500/2500/3500/4500 ms) and two target locations (cued location/uncued location).

3. Results

Only response times (RTs) for correct test trials were analyzed. The response time data for each subject were first submitted to a descriptive statistics and RTs beyond 3 standard deviations were excluded. A lower RT limit of 120 ms was further employed to exclude those RTs that are physiologically impossible. Mean RTs as a function of cue-target SOA and target location are shown for each stimulus eccentricity in Fig. 2A.

An analysis of variance (ANOVA) with stimulus *eccentricity* (7° and 21°), *SOA* (500 ms, 1500 ms, 2500 ms, 3500 ms, 4500 ms) and target *location* (cued location, uncued location) as within-subjects factors was conducted on the mean RT data. The main effect of *eccentricity* was significant [$F(1,24) = 44.009, P < 0.001, \eta_p^2 = 0.647$], revealing a slower RT for more peripheral locations which was consistent with previous observations [27]. Furthermore, the *eccentricity* effect interacted with target *location* [$F(1,24) = 23.437, P < 0.001, \eta_p^2 = 0.494$], showing a significantly larger IOR effect (mean RT for cued location trials minus mean RT for uncued