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Near complete interocular transfer of the attentional repulsion effect

Melisa Menceloglu[a], Marcia Grabowecky[b], Satoru Suzuki[b,*]

[a] Department of Psychology, Northwestern University, Evanston, IL, USA
[b] Department of Psychology and Interdepartmental Neuroscience Program, Northwestern University, Evanston, IL, USA

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ABSTRACT

During a brief period following attention capture by an abrupt-onset cue, a briefly presented item in the vicinity appears to be displaced away from the focus of attention. This effect, termed the attentional repulsion effect (ARE), can be induced with various ways of focusing attention (e.g., color pop-out, an auditory cue, voluntary focusing), and can be measured in various ways (e.g., as a vernier offset, shape deformation, action error). While most prior results on ARE have confirmed its close relationship with attention mechanisms, DiGiacomo and Pratt Vision Research 64 (2012) 35–41 reported no interocular transfer of ARE, placing ARE's operational locus at the level of monocular processing in V1 and/or LGN. DiGiacomo's and Pratt's result is surprising because even local pattern adaptation effects thought to be mediated by V1 show 50%–80% of interocular transfer. How could it be that a strongly attention-dependent effect is exclusively mediated by monocular processes? It was thus important to replicate DiGiacomo's and Pratt's surprising results using a transient-free mirror-based stereoscope and a broader method where ARE was measured with both vertical and horizontal vernier offsets. Our results demonstrate a nearly complete interocular transfer of ARE, with stronger ARE obtained with horizontal than with vertical verniers, implying that ARE may be hemifield dependent. We speculate that the null ARE result reported by DiGiacomo and Pratt in their dichoptic condition may be due to a statistical anomaly or to a potential visual artifact generated by the eye shutters that were used to present dichoptic stimuli.

1. Introduction

The following is a typical example of the attention repulsion effect (see the left sequence in Fig. 1). When a small circle is briefly flashed (e.g., 30 ms) in the upper right quadrant (*Frame 2*), for example, a subsequently flashed pair of vertical line segments aligned across the fixation point appears distorted such that the upper line appears shifted to the left of the lower line (*Frame 4*). A standard explanation of this effect (e.g., Suzuki & Cavanagh, 1997) is that a briefly flashed circle captures exogenous attention and the attentional focus causes an expansive distortion of the spatial representation around it (arrows in *Frame 3*), so that a subsequently flashed item within the distorted field appears to be shifted away from the focus of attention (*Frame 4*). If the subsequently flashed stimulus is a vertical vernier, the top element should appear displaced leftward (*Frame 4*, left), whereas if the subsequently flashed stimulus is a horizontal vernier, the right element should appear displaced downward (*Frame 4*, right).

Based on the stimulus sequence per se, this phenomenon could reflect a relatively long-range sequential spatial interaction that is repulsive. The reason why this phenomenon was originally termed the attentional repulsion effect (ARE) is as follows. First, the transient time course of the magnitude of the displacement effect (peaking at about 100–300 ms following the onset of the attention-capturing stimulus) is similar to the transient time course of processing benefits arising at the stimulus-captured focus of attention measured with RT and accuracy. Second, the ARE time course can be prolonged by the sustained engagement of voluntary attention. Third, potential roles of spatial adaptation and apparent motion were ruled out (Suzuki & Cavanagh, 1997). Subsequent research has overall supported the hypothesis that ARE is closely associated with attention mechanisms. For example, ARE occurs relative to a color-singleton item which is known to capture attention (Pratt & Arnott, 2008). ARE also occurs relative to the location of a sound cue that captures spatial attention without generating visual interactions (Arnott & Goodale, 2006). Nevertheless, not all types of attention allocation that generate measurable RT effects induce ARE. For example, Gozli and Pratt (2012) reported that the prioritized attention allocation to stimuli containing task relevant features influenced RT, but did not affect ARE. Future research may determine the critical properties of attention allocation (e.g., spatial extent of focus, effort to withhold saccade to the focus) necessary to generate the spatial

* Corresponding author at: Department of Psychology and Interdepartmental Neuroscience Program, Northwestern University, 2029 Sheridan Road, Evanston, IL 60208, USA.

E-mail address: satoru@northwestern.edu (S. Suzuki).

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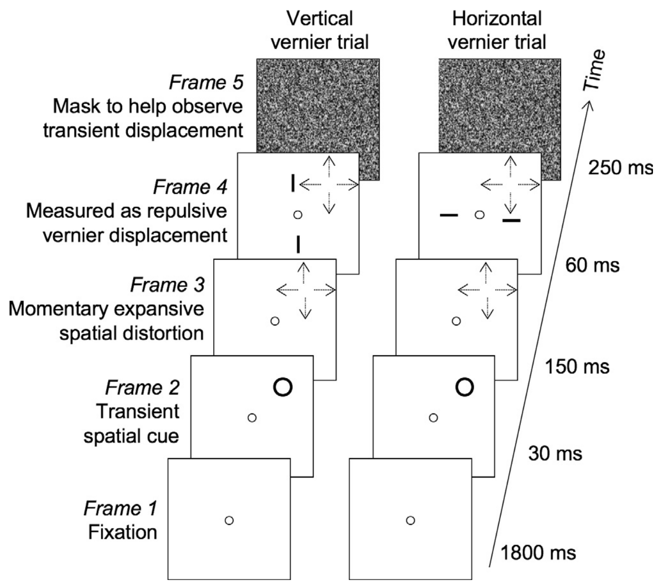

Fig. 1. An illustration of the basic logic of the "attentional repulsion effect" (ARE) and the design of the current study. *Frame 1*. Participants fixate the central fixation point. *Frame 2*. A transient cue is presented to capture exogenous attention. *Frame 3*. The focused attention hypothetically expands the surrounding spatial representation (arrows). *Frame 4*. This expansive spatial distortion can be measured as a repulsive perceptual displacement of an item flashed in the vicinity (ARE). In this example, the repulsive displacement is measured as a perceived leftward (left panel) or downward (right panel) shift of the proximate vernier element relative to the distant vernier element. *Frame 5*. The mask helps to observe the transient displacement effect. In the current experiment, the brief onset cue appeared in any quadrant, the vernier was either vertical or horizontal, and the proximate vernier element was randomly misaligned relative to the fixation point in either direction while the distant (reference) vernier element was always aligned with the fixation point. At the end of each trial, participants responded whether the vernier elements were shifted clockwise or counterclockwise in a 2-alternative forced-choice manner.

distortion underlying ARE.

The most surprising report on ARE has been of a complete lack of interocular transfer (DiGiacomo & Pratt, 2012). This result is puzzling for the following reasons. ARE is a relatively long-range effect where the distance between the attention cue and the probe can be as much as 12° of visual angle (e.g., Kosovicheva, Fortenbaugh, & Robertson, 2010). In contrast, strongly monocular neurons which would be necessary to explain a complete lack of interocular transfer are located in V1 and LGN where neural receptive fields are much smaller than 12° (~1°; e.g., Sceniak, Chatterjee, & Callaway, 2006; Nauhaus, Nielsen, & Callaway, 2016). Neural receptive fields in V1 spatially interact depending on contour feature configurations and tasks to form larger association fields (e.g., McManus, Li, & Gilbert, 2011). However, there is no reason to suspect nor is there any evidence to suggest that these association fields are limited to strictly monocular neurons which are a minority in V1 (e.g., Hubel & Wiesel, 1968). Given that ARE can be induced by an auditory attention cue (Arnott & Goodale, 2006), it may be mediated by multimodal neurons in superior colliculus (e.g., Meredith & Stein, 1986), but colliculus receptive fields are predominantly binocular (e.g., Cynader & Berman, 1972). Furthermore, location-specific visual adaptation effects specific to orientation and spatial frequency, thought to be mediated by V1 neurons, substantially transfer (50%–80%) between the two eyes (e.g., Blakemore & Campbell, 1969; Gilinsky & Doherty, 1969; Blake & Fox, 1972; Bjorkland & Magnussen, 1981). It is thus surprising that ARE, which is less location or feature specific than these pattern aftereffects, would be completely monocular.

For these reasons, given that ARE is a highly attention-dependent and long-range spatial distortion effect, if it were indeed mediated entirely by monocular mechanisms, that conclusion would have profound impact on how we understand the relationship between spatial coding, attention, and monocular mechanisms. While partial interocular transfers of orientation and spatial frequency aftereffects have been replicated by multiple studies, only one study has reported the complete lack of interocular transfer of ARE. It is thus important to replicate the result.

We made a few modifications to DiGiacomo's and Pratt's (2012) paradigm. One is the use of a mirror-based stereoscope. DiGiacomo and Pratt (2012) dichoptically presented their stimuli using a pair of goggles with shutters that were synchronized with stimulus presentations. Although they included a control experiment to show that inserting transients during the monoptic condition did not interfere with ARE, it would be beneficial to replicate the lack of dichoptic ARE in the absence of any spurious transients using a mirror-based stereoscope. Another modification we made was to present single attention cues and measure ARE with both vertically and horizontally configured verniers (Fig. 1). DiGiacomo and Pratt (2012) always used double attention cues presented at diagonally opposite quadrants to increase the magnitude of ARE and measured ARE with a vertically configured vernier, as did most other studies on ARE (e.g., Pratt & Turk-Browne, 2003; Pratt & Arnott, 2008; Kosovicheva et al., 2010; Chien & Watanabe, 2013). Nevertheless, the cleanest way to measure ARE would be to use a single cue to induce a single focus of attention, and if focused attention generates an expansive spatial distortion, the effect should be equivalently measured with either a vertically or horizontally configured vernier (Fig. 1). If vertical verniers were exclusively used, ARE could potentially be influenced by observers' consistent expectation of vertical verniers. We thus used single attention cues and randomly intermixed vertical and horizontal verniers across trials.

2. Methods

2.1. Participants

Twenty-eight Northwestern University undergraduate students (18 female), between the ages of 18 and 20 ($M = 18.61$, $SD = 0.79$) gave informed consent to participate in the experiment for partial course credit. All participants had normal or corrected-to-normal visual acuity and were tested individually in a dimly lit room. The experiment was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

2.2. Stimuli and procedure

The display monitor had 1280-by-1024 pixel resolution running at an 85 Hz refresh rate. All experimental stimuli were presented within a 7.55°-by-7.55° dark (0.22 cd/m^2) square region containing a central fixation circle (0.09° radius, 8 cd/m^2), embedded within a lighter (15.2 cd/m^2) background. The square region was duplicated on the left and right sides of the monitor and were fused using a stereoscope consisting of four front-surface mirrors and a central divider to present stimuli monoptically and dichoptically. The viewing distance was 110 cm.

At the start of the experiment, participants viewed a dichoptically presented pair of vertically aligned line segments. They fine-tuned the mirror angles so that the line segments appeared to be precisely aligned. The dark square region with the central fixation circle (remaining throughout each trial except during the mask) was then binocularly presented. Following 1800 ms of the fixation display, a circular attention cue (0.63° radius, 45 cd/m^2) was flashed for 30 ms in one of the four quadrants at 3.56° retinal eccentricity. After a 150 ms inter-stimulus interval, either the vertical or horizontal vernier stimulus (each vernier element 1.26° long and 0.02° wide, presented at 2.52° retinal eccentricity) was presented for 60 ms and was immediately followed by a Gaussian luminance-noise mask lasting 250 ms (note that