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Changes in orientation discrimination at the time of saccadic eye movements

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ABSTRACT

Perceptual performance has been known to change around the time of saccadic eye movement. In the current study, we measured the accuracy and sensitivity of orientation discrimination of bar stimuli presented during fixation and before saccadic eye movements. Human participants compared the orientations of the test and reference bar stimuli with the head erect in a two-interval forced choice task. For the targets presented during steady fixation, the accuracy and sensitivity of orientation discrimination were better near the cardinal than oblique axes, a perceptual anisotropy known as the oblique effect. For the targets presented during the 100 ms interval immediately before a saccade was executed, the anisotropy decreased mainly due to reduction in sensitivity for cardinal orientations. Directing attention to the goal location of the impending saccade emulated the saccadic effects on orientation discrimination for the targets at saccadic goal, suggesting that the saccadic effects on orientation discrimination are partly mediated by the shift of spatial attention that accompanies the saccade. These results were in line with the anti-oblique effect that perceptual judgment of motion direction along the oblique angle becomes relatively accurate for motion targets presented before saccadic eye movements [Lee, J., & Lee, C. (2005). Changes in visual motion perception before saccadic eye movements. *Vision Research, 45*(11), 1447–1457].

1. Introduction

Considerable evidence indicates that perception changes around the time of saccadic eye movements (Awater & Lappe, 2004; Burr, Morrone, & Ross, 1994; Cai, Pouget, Schlag-Rey, & Schlag, 1997; Dassonville, Schlag, & Schlag-Rey, 1992; Honda, 1991; Lee & Lee, 2005; Morrone, Ross, & Burr, 2005; Ross, Morrone, & Burr, 1997; Yarrow, Haggard, Heal, Brown, & Rothwell, 2001). As each saccade shifts retinal image, it is natural that spatial aspects of perceptual change have received a particular attention in relation to maintenance of perceptual continuity. A notable example is spatial mislocalization in which a visual target briefly presented immediately before, during, or after a saccadic eye movement is systematically mislocalized (Ross, Morrone, Goldberg, & Burr, 2001; Schlag & Schlag-Rey, 2002). While neural correlates of perceptual changes are not completely understood, modulation of neural activity around the time of a saccadic eye movement has been documented in various visual cortical areas including the primary visual cortex (Bakola, Gregoriou, Moschovakis, Raos, & Savaki, 2007; Krekelberg, Kubischik, Hoffmann, & Bremmer, 2003; Moeller, Kayser, & Konig, 2007; Nakamura & Colby, 2000; Noda, Freeman, & Creutzfeldt, 1972; Park & Lee, 2000; Rajkai et al., 2008; Super, van der Togt, Spekreijse, & Lamme, 2004). The modulation of neural activity suggests that a wide range of perceptual aspects change around the time of saccadic eye movements.

In a previous study, we reported that judgment error for the direction of visual motion was larger for oblique than cardinal directions during fixation, but before a horizontal saccadic eye movement was executed, this oblique effect was absent for the most part and perceptual judgment of oblique directions became relatively accurate (Lee & Lee, 2005). Preparation for saccades appeared to improve the accuracy of direction judgment for visual motion in the visual field ipsiversive to impending saccades. Since signals coding motion direction are related to the orientation mechanism (Geisler, 1999; Geisler, Albrecht, Crane, & Stern, 2001), and the classic oblique effect consistently manifests itself in orientation discrimination (Westheimer & Beard, 1998), we tested in the current study whether similar changes in orientation discrimination occur for the targets presented before saccades. Specifically, we derived from psychometric curves based on a two-interval forced choice task, discrimination accuracy and sensitivity for stimulus orientation during steady fixation and examined changes in discrimination performance when saccadic eye movements were made.

2. Methods

2.1. Subjects

Four subjects (aged 22–25) participated in the study. They had normal or corrected-to-normal vision with no known astigmatism.

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For each, the procedures and possible consequences of the experiments were explained, and informed consent to participate was obtained.

2.2. Apparatus

Visual stimuli were presented on a 24-in. flat CRT monitor (Sony GDM-W900) with the spatial resolution of 800 × 600 pixels at the refresh rate of 100 Hz. The subjects, sitting with their head restrained with a bite bar and dental impression material, viewed the monitor with natural pupils at a distance of 60 cm. At this distance the monitor display spanned 44 × 28 deg. The horizontal position of the right eye was monitored with an infra-red reflection method (IRIS, Skalar Medical), sampled at 500 Hz with a 16-bit resolution, and stored for off-line analysis. The experiment was controlled by a computer program written in Matlab (The Mathworks) using psychophysics toolbox (Brainard, 1997; Pelli, 1997). All experiments were carried out in a dark and sound-attenuated room. The background luminance of the monitor was measured 0.00 cd/m^2.

2.3. Procedures

The performance of orientation discrimination was tested in six experimental conditions (Fig. 1).

2.3.1. Fixation condition

The fixation condition was used to establish the baseline performance of orientation discrimination during steady fixation. After a tone signaled the start of a trial, the fixation dot (red square, 0.25 × 0.25 deg, 0.30 cd/m^2) appeared at the center of the screen, on which the subject was instructed to maintain fixation. With a delay of 1200 ms after the eye entered within a 4 × 4 deg electronic window around the fixation target, the test stimulus bar, shown in green (10 × 0.25 deg, 0.05 cd/m^2), of a variable orientation appeared for 50 ms with the center of the bar either at 10 deg to the left or right of the fixation target. After a delay of 1200 ms, the reference stimulus, shown in red (10 × 0.25 deg, 0.05 cd/m^2), was presented centering at the same center location of the test stimulus. The delay duration was chosen to minimize the potential interference of the afterimage of the test stimulus left on the monitor and to maintain memory of the test stimulus. The luminance level of the test and reference stimuli was chosen to keep a proper detection level of each subject without a significant afterimage under the condition of dark adaptation. The use of color stimuli was to aid response protocol. Both luminance and iso-luminant stimuli are thought to produce similar orientation discrimination performance (Reisbeck & Gegenfurtner, 1998). The orientation of the test stimulus was pseudo-randomly varied in steps of 22.5 deg between 0 deg and 157.5 deg, with 0 deg to the right and 90 deg to the top. The orientation of the reference stimulus was pseudo-randomly varied within ±6 deg from the orientation of the target stimulus with a step of 2 deg. All the test and reference stimuli were smoothed with a Gaussian filter to prevent an aliasing effect of a static line stimulus on a computer monitor. The subject was instructed to maintain fixation until the reference stimulus was presented. The subject's task was to judge whether the reference stimulus rotated clockwise (CW) or counterclockwise (CCW) with respect to the test stimulus by shifting a joystick to the right or left. The reference stimulus disappeared on the subject's response, and the next trial started with an inter-trial interval of 1.5 s.

In all experimental conditions, we turned on the overhead light between blocks each of which lasted about 5–7 min with more than 100 trials, to prevent potential contamination from dark adaptation. None of subjects reported that the display edge was visible during the experiment. To test further any residual effects of dark adaptation, we divided the trials of the fixation condition into the earlier and later groups within the each block, compared the two groups in terms of discrimination accuracy and sensitivity measures to be described below, and found no statistically significant differences in any case.

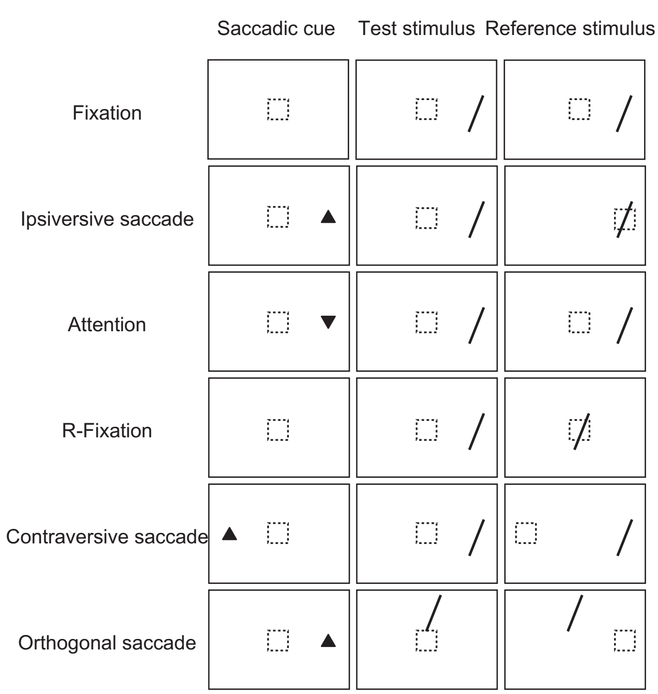

Fig. 1. Six experimental conditions. Dotted square represents location of fixation window at the time of presentation of saccadic cue, test and reference stimuli. Main goal of the current study was to compare discrimination performance between fixation and ipsiversive saccade conditions. The spatial locations of test and reference stimuli were identical in both fixation and ipsiversive saccade conditions, but their retinal locations were not. R-fixation condition was a control for this and retinal locations of test and reference stimuli in this condition matched those of ipsiversive saccade condition. See text for details.

2.3.2. Saccade condition

This was the main experimental condition, and its purpose was to determine the accuracy and sensitivity of orientation discrimination for a static bar stimulus presented immediately before a saccade is made toward the stimulus location. All aspects of the saccade condition were the same as in the fixation condition except the procedures related to triggering a saccade. After a tone signaled the start of trial, the fixation dot appeared at the center of the screen. With a delay of 1200 ms after the eye entered within a 4 × 4 deg electronic window around the fixation target, the fixation dot disappeared and a saccadic cue (an equilateral triangle pointing upward, 0.7 × 1.3 deg, 0.25 cd/m^2) appeared for 50 ms centering either at 10 deg to the left or right of the fixation target. With a delay of 1000 ms after the saccadic cue disappeared, a tone with duration of 50 ms signaled the subject to make a saccadic eye movement to the remembered location of the saccadic cue as quickly and precisely as possible. The use of an auditory cue for triggering the saccade was to prevent a potential visual interference from the saccadic cue with discrimination performance. With a variable delay (90, 140 or 170 ms) after the tone onset, the test stimulus appeared for 50 ms in such a way that the center of the test stimulus was at the location of the center of saccadic cue. The temporal gap between the auditory cue and the test stimulus was chosen to bring the target stimulus near the saccade onset. For this, the saccade latency of the previous trial was taken into