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Contrast dependence of saccadic blanking and landmark effects

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ABSTRACT

Two phenomena have been reported to affect the perceived displacement of a visual target during saccadic eye movements: the blanking effect and landmark effect. In the blanking effect, temporarily blanking the target after a saccade improves displacement judgments. In the landmark effect, illusory target displacement occurs when a continuously presented landmark is displaced during a saccade, and the target is temporarily blanked after the saccade without displacement. We show that the strengths of the blanking and landmark effects vary with stimulus contrast. In the blanking effect, target displacement detection rate increased with luminance contrast of the target. In the landmark effect, illusory target displacement decreased with luminance contrast of the target. Moreover, the landmark effect was found even for stimuli without luminance contrast (equiluminant color stimuli), while the blanking effect disappeared. These results can be attributed to a reduction in sensitivity of target displacement by a reduction of luminance contrast, which suggests that changes in luminance, or transient signals, play a critical role in visual stability across saccades.

1. Introduction

Saccadic eye movements cause the image of the visual world to shift on the retina, intermittently disrupting retinal image stability. Despite this instability, we perceive the visual world as stable. How does the visual system achieve visual stability when retinal images are frequently displaced by saccades? One possibility is that the visual system assumes that the visual world does not change during saccades (Mackay, 1962). This assumption is supported by the inability to detect small displacements during saccades (Bridgeman, Hendry, & Stark, 1975), referred to as saccadic suppression of displacement, motion, or transient signals (Bridgeman et al., 1975; Burr, Morrone, & Ross, 1994; Shioiri & Cavanagh, 1989; Uchikawa & Sato, 1995). Consequently, the visual world appears stable and uninterrupted.

However, the mechanisms for visual stability across saccades involve more than saccadic suppression of displacement, as suggested by two phenomena influencing the perception of displacement during saccades. First, previous studies demonstrated that brief blanking of a target after a saccade produces a large improvement in displacement judgment (the 'blanking effect') in cases where the target moves to a new location during the saccade (Deubel, Schneider, & Bridgeman, 1996, 2002). This suggests that postsaccadic target blanking may prevent saccadic suppression of image displacement. The blanking effect may reflect a general property of saccadic visual processing rather than an effect specific to displacement. A recent study reported that postsaccadic target blanking also facilitates spatial frequency discrimination (Weiss, Schneider, & Herwig, 2015), while another study reported that postsaccadic target blanking does not improve sensitivity for movements of an object (Gysen, Verfaillie, & De Graef, 2002). Second, previous studies have reported that a landmark presented near a stationary, temporarily blanked saccadic target induces an illusory target displacement if the landmark is displaced during the saccade (the 'landmark effect') (Deubel, 2004; Deubel, Bridgeman, & Schneider, 1998). Both the blanking and landmark effects involve a transient change in luminance. Thus, blanking the target after the saccade may activate motion- and/or transient-sensitive systems, which are usually suppressed by saccades. If this is true, the activation of the motion- and transient-sensitive systems could improve the accuracy of target displacement judgments (i.e., facilitate the blanking effect) and strengthen the target-related signals to reduce the illusory perception of target displacement induced by landmark displacement.

The magnocellular pathway, which responds preferentially to luminance transients or motion stimuli (Merigan, Byrne, & Maunsell, 1991; Schiller, Logothetis, & Charles, 1990), may be involved in saccadic suppression of image displacement as well

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as in the blanking and landmark effects. For instance, a previous study demonstrated that saccadic suppression of image displacement depends on luminance contrast and becomes stronger with luminance stimuli than with equiluminance chromatic stimuli (Bridgeman & Macknik, 1995), suggesting that the magnocellular pathway is selectively affected in saccadic suppression of image displacement. This implies that luminance contrast is important for perisaccadic perceptual phenomena, including the blanking and landmark effects. To our knowledge, however, no study has examined the effects of luminance contrast on the blanking effect and on the landmark effect.

In this study, we investigated the influence of target luminance contrast on the blanking effect (Experiment 1) and the landmark effect (Experiment 2). We also investigated the effect of contrast using equiluminant chromatic stimuli (Experiment 3). The purpose of the experiments was to examine the influence of transient signals caused by target blanking and reappearance after a saccade on each of these phenomena. If transient signals are crucial for displacement detection across saccades, we would expect that the strengths of the blanking and landmark effects would vary with luminance contrast, as higher contrast produces stronger transient signals. This study reports that the increase in the blanking benefit of target displacement with increasing target contrast for the blanking effect is similar to that for the landmark effect, and finds that the landmark effect occurs even for equiluminant chromatic stimuli.

2. Experiment 1: effect of target contrast on the blanking effect

2.1. Methods

2.1.1. Observers

Five male observers from 24 to 38 years old (mean age, 29 years) with normal vision participated in this study and gave informed consent in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Four of them were naive to the purpose of this study. The other subject was one of the authors (KM). This study was approved by the Ethics Committee of the Research Institute of Electrical Communication, Tohoku University.

2.1.2. Apparatus

The observer's head was fixed with a combination forehead and chin rest. Visual stimuli were presented on a CRT display (GDM-F520, Sony) with a refresh rate of 100 Hz. The viewing distance was 60 cm. The display subtended 38° high and 49° wide, and was controlled by a visual stimulus generator (ViSaGe, Cambridge Research Systems).

A limbus-tracking device (T.K.K.2930a, Takei Scientific Instruments Co., Ltd.) consisting of an infrared-emitting diode and two photodiodes was used to measure horizontal movements of the observer's right eye. The analog signal from the device was digitized at a sampling rate of 100 Hz and recorded on a computer. We differentiated the trajectory of the eye position to obtain the velocity of eye movement. The onset of a saccade was defined as the time at which eye velocity exceeded 30°/s. Saccade latency was defined as the period between the onset of target and the onset of saccade.

2.1.3. Calibration of eye movement

Each session started with a calibration procedure where the observer fixated on five dots presented sequentially on a horizontal center line of the display and pushed a button after each fixation was completed. Horizontal eye positions were expressed as voltages when the button was pushed. A linear regression procedure determined the relationship between voltage and dot position.

2.1.4. Stimuli

Fig. 1 shows the arrangement of visual stimuli in Experiment 1. First, a circular fixation cue (0.4° in diameter, 27.4 cd/m^2) was presented 4° to the left of the display center. The saccadic target, which was the same as the fixation cue, was presented 4° to the right of the center. The luminance of the saccadic target varied randomly between set values of 24.0, 25.1, 27.4, 32.0, and 41.1 cd/m^2 from trial to trial, while background luminance was constant at 22.8 cd/m^2. Thus, the contrast of the saccadic target varied randomly between 5%, 10%, 20%, 40%, and 80%.

The color of the stimuli was yellow [CIE x, y chromaticity coordinates: 0.401, 0.518].

2.1.5. Procedure

Fig. 1 shows the stimulus sequence of a blanking effect trial. Initially, a fixation point was presented 4° to the left of the display center. The observer fixated on the fixation point and pressed a button to start the trial. After a randomly selected delay between 500 and 1300 ms, the fixation point was extinguished and the saccadic target appeared 4° to the right of the display center, with variable luminance contrast. The observer was instructed to make a saccade toward this target as quickly as possible. In the 'blank' condition, the target was blanked for 100 ms after onset of the saccade (Fig. 1a). When the target reappeared, it was displaced by 0.15° to the left or right. The target was extinguished 200 ms after it reappeared. In the 'no blank' condition (Fig. 1b), the target was continuously present, but was displaced 0.15° to the left or right just after the saccade onset. In these 'no blank' trials, the target was extinguished 300 ms after displacement. The observer reported whether the target was displaced to the left or to the right. Each observer performed four sessions. Each session consisted of 50 trials of the 'blank' condition and 50 trials of the 'no blank' condition. Trials were excluded from analysis if saccade latency was shorter than 120 ms or longer than 400 ms, or if the blanking of the target occurred after saccade offset. Across participants, saccade latency was shorter than 120 ms or longer than 400 ms in 2.84% of trials, and the blanking of the target occurred after the saccade offset in 2.75% of trials; thus, less than 6% of trials were excluded from the analysis.

2.2. Results and discussion

Fig. 2 shows the percentages of correct displacement discriminations as a function of target contrast. The solid and open symbols represent the 'blank' and 'no blank' conditions, respectively. Fig. 2a–e present the responses of each observer, and Fig. 2f shows the mean data of all five observers. Discrimination of target displacement improved progressively with increasing target contrast in the 'blank' condition. In the 'no blank' condition, however, discrimination of target displacement improved only slightly with increasing target contrast. The improvement of discrimination of target displacement by a target blank at a high contrast is consistent with previous findings (Deubel et al., 1996, 2002). Repeated measures analysis of variance (ANOVA) of group mean data with two presentation conditions ('blank' and 'no blank') and five contrast levels (5%, 10%, 20%, 40%, and 80%) revealed significant main effects of presentation condition [$F(1, 4) = 28.29$, $p < 0.01$] and contrast level [$F(4, 16) = 20.28$, $p < 0.001$]. There was also an interaction between presentation condition and contrast level [$F(4, 16) = 3.94$, $p < 0.05$]. The results suggest that the blanking effect depends on target contrast and grows in strength as the contrast of the target increases.