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Luminance contrast in the background makes flashes harder to detect during saccades

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ABSTRACT

To explore a visual scene we make many fast eye movements (saccades) every second. During those saccades the image of the world shifts rapidly across our retina. These shifts are normally not detected, because perception is suppressed during saccades. In this paper we study the origin of this saccadic suppression by examining the influence of luminance borders in the background on the perception of flashes presented near the time of saccades in a normally illuminated room. We used different types of backgrounds: either with isoluminant red and green areas or with black and white areas. We found that the ability to perceive flashes that were presented during saccades was suppressed when there were luminance borders in the background, but not when there were isoluminant color borders in the background. Thus, masking by moving luminance borders plays an important role in saccadic suppression. The perceived positions of detected flashes were only influenced by the borders between the areas in the background when the flashes were presented *before* or *after* the saccades. Moreover, the influence did not depend on the kind of contrast forming the border. Thus, the masking effect of moving luminance borders does not appear to play an important role in the mislocalization of flashes that are presented near the time of saccades.

1. Introduction

While exploring a visual scene our eyes make many fast movements (saccades) to shift our point of gaze to objects of interest. During each saccade, the image of the world shifts across our retina. Under normal circumstances people do not perceive these shifts. The reduction in visual sensitivity during saccades that is responsible for the shifts themselves not being noticed is called saccadic suppression (e.g. Burr, Morrone, & Ross, 1994; Campbell & Wurtz, 1978; Ross et al., 2001; Shioiri & Cavanagh, 1989; Uchikawa & Sato, 1995; Watson & Krekelberg, 2009; Wurtz, 2008). Two kinds of mechanisms could contribute to saccadic suppression (reviewed in Castet (2010)): an active suppression driven by an extra-retinal corollary discharge and visual masking of the motion-blurred stimuli by the static images before and after the saccade. It seems likely that in normal high luminance contrast environments visual masking is the dominant mechanism (Castet, Jeanjean, & Masson, 2002; Wurtz, 2008).

Stimuli that were flashed on a uniform background during saccades were detected, even when their luminance contrast was just above threshold (Georg, Hamker, & Lappe, 2008). However, flashes presented during saccades on a background with a single additional rectangle of another color were not detected (Lappe et al., 2006). This difference implies that masking is very effective in suppressing vision during saccades, because a single rectangle of a different color is quite a minimal mask. Perhaps the fact that the border between the differently colored areas moves rapidly across the retina during the saccade makes the response to the flash harder to detect. However, we have recently shown that flashes presented during a saccade can be perceived despite large color differences in the background (Maij, Brenner, & Smeets, 2011). A difference between the studies that might be responsible for the difference in saccadic suppression is that we (Maij, Brenner, & Smeets, 2011) used isoluminant colored regions in the background, whereas Lappe and colleagues (2006) used a combination of color and luminance contrast. Do luminance borders specifically mask transient stimuli when they shift across the retina?

It is known for decades that visual objects presented briefly before, during or after saccades are systematically mislocalized (e.g. Honda, 1989; Lappe, Awater, & Krekelberg, 2000; Maij, Brenner, & Smeets, 2009; Mateeff, 1978; Matin, Matin, & Pola, 1970; Matin & Pearce, 1965; Ross, Morrone, & Burr, 1997; Van Wetter & Van Opstal, 2008). Peri-saccadic mislocalization and saccadic suppression have been seen as related phenomena (Diamond, Ross, & Morrone, 2000; Michels & Lappe, 2004). The time courses of suppression and mislocalization support a common origin, which has been

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suggested to be the corollary discharge component of saccadic suppression (Diamond, Ross, & Morrone, 2000; Michels & Lappe, 2004). However, if suppression is mainly due to masking (Castet, 2010) and mislocalization is mainly due to the way in which retinal and extra-retinal signals are combined (Maij, Brenner, & Smeets, 2011; Morrone, Ross, & Burr, 1997), the two phenomena cannot be very tightly related.

Of course they will not be completely independent, for instance because backward masking is enhanced by corollary discharge signals (Ibbotson & Cloherty, 2009; Ibbotson & Krekelberg, 2011), but is there any evidence that luminance borders sweeping across the retina influence peri-saccadic mislocalization in a manner that can be linked to their effect on saccadic suppression?

In this experiment we directly compare the effects of isoluminant color borders in the background with the effects of luminance borders in the background on the perception of flashes presented around the time of saccades. The flashes always differ from the background in both color and luminance. We also investigated whether the flash's location relative to the border is critical: does it matter whether the border shifts across the flash location just before or just after the presentation of the flash?

2. Methods

2.1. Subjects

We conducted the experiment in a room illuminated by light from several fluorescent lamps. Six subjects volunteered to take part in the experiment (including one of the authors). Only the author was aware of the specific conditions. All subjects had normal or corrected-to-normal vision. The study is part of a research program that was approved by the ethics committee of the Faculty of Human Movement Sciences.

2.2. Experimental setup

Visual stimuli were presented on a touch screen (EloTouch CRT 19 in., 1024×768 pixels, 36×27 cm, 85 Hz) using the Psychophysics Toolbox in MATLAB (Brainard, 1997). The screen was orthogonal to the line of sight, at a distance of 50 cm and subtending $40° \times 30°$ of visual angle. Eye movements were registered using an Eyelink II (SR Research Ltd., Mississauga, Ontario, Canada) at a sample frequency of 500 Hz using the Eyelink Toolbox (Cornelissen, Peters, & Palmer, 2002). Subjects were asked to follow a 0.5° diameter jumping dot with their eyes. The dot was presented at a new position every 400 ms. It jumped in steps of 12° across the screen. All except the last jump displaced the dot randomly in one of eight radial directions: horizontal, vertical and diagonal (but never choosing a direction that would bring the dot within 115 pixels of the edge of the screen). The last jump of the dot was always a horizontal one, it either started 6° to the left of the midline and ended 6° to the right or vice versa.

After a series of 3, 4, 5 or 6 jumps (random with equal probabilities) a $0.5° \times 12.3°$ vertical bar was flashed for one frame at one of three different locations. The locations of the flashed bar were defined with respect to the 12° displacement between the last two positions of the dot. The flash was presented along an invisible line through these positions, at −20%, 20%, or 130% of the dot's last jump. The dot was removed 50 ms after the last jump, which usually took place before the flash presentation. The trial ended when the subject indicated where he or she had perceived the flash by touching the screen at that location. The subject was instructed to touch a corner of the screen if he or she did not perceive the flash.

The backgrounds could consist either of three segments (red and green or black and white), or could be uniform. If the background consisted of three segments, there were two segments of one color at the two sides, with a segment of a different color or luminance extending vertically across the whole screen between them. The central segment extended horizontally from the dot's position before the last jump (6° from the midline) to a position beyond the saccade target (8.4° to the opposite side of the midline; see Fig. 1). We presented a red jumping dot and a green flashed bar (of the same luminance) on black and white backgrounds, and we presented a black jumping dot and a white flashed bar on (isoluminant) red and green backgrounds.

On trials with a border, for the −20% location of the flash, a border passed the flash's retinal location almost immediately after the flash if the flash was presented during the saccade. For the other two flash locations the border passed the flash's retinal location just before the flash. For the 20% flash location the expected *percept* did not cross the border, whereas for the other two it did.

There were eight possible backgrounds (Fig. 1), but we will not consider distinctions between red (44 cd/m^2; CIE_{xy} = 0.59, 0.35) and green (matched individually to red in luminance; CIE_{xy} = 0.29, 0.57) or between black (8 cd/m^2) and white (126 cd/m^2; CIE_{xy} = 0.28, 0.32) except in forming the borders, so we only consider there to be two patterns for the red–green and for the black–white surfaces: uniform or segmented. These four combinations (uniform red–green; segmented red–green; uniform black–white; segmented black–white) will be referred to as conditions. Isoluminance for red and green was determined individually by flicker photometry.

2.3. Calibration

Before each session the subject was asked to calibrate the Eyelink II using the standard nine-point calibration procedure. To synchronize the eye movement recordings with the images presented on the screen, we presented two flashes at the same time. One of them was the flash that the subject had to localize. The other flash (in the lower right corner of the screen) was used to synchronize the eye movement recordings with the images presented on the screen, and was not visible to the subject. We measured the moment of this second flash with a photo-diode that was attached to the lower right corner of the screen. The photo-diode sent a signal to the parallel port of the Eyelink computer. This signal was registered in the data file on the Eyelink computer. The temporal relationship between such a record and the record of the eye orientation at the moment of the flash was previously determined by using the photo-diode to drive an infrared lamp that 'blinded' one of the Eyelink's infrared cameras. Because the photo-diode was placed in the lower right corner, and the flash was presented at different locations on the screen, the real timing was only known to within a few milliseconds (we did not correct for the temporal effects of variation in the position of the flash on the screen). For trials in which no signal was registered on the parallel port (due to technical failure; 3% of all trials) we used the average delay (14.9 ms) between the record of the command to show the flash (that was also recorded on the Eyelink computer) and the record of the signal on the parallel port on trials in which there was such a signal, to estimate when the flash had occurred.

2.4. Procedure

Because the suppression of the flash only occurs around the moment of the saccade, we wanted to present as many flashes as possible at about that time. We used the saccadic reaction times on previous trials to predict the saccade onset (Maij, Brenner, & Smeets, 2009). At the predicted saccadic reaction time the bar was flashed on the screen for one frame at one of the possible flash locations (defined in relation to the last displacement of the dot).