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How post-saccadic target blanking affects the detection of stimulus displacements across saccades

David E. Irwin*, Maria M. Robinson

Department of Psychology, University of Illinois, United States

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ABSTRACT

When a visual stimulus is displaced during a saccade the displacement is often not noticed unless it is large compared to the amplitude of the eye movement. Displacement detection is improved, however, if a blank intervenes between saccade target offset and the presentation of the displaced post-saccadic stimulus. This has been interpreted as evidence that precise information about eye position and accurate memory for the position of the pre-saccadic target are available immediately after saccade offset, but are overridden by the presence of the post-saccadic stimulus if it is present when the eyes land. In the current set of experiments we examined in more detail how blanking contributes to the increase in displacement sensitivity. In two experiments we showed that the presentation of a blank interval between saccade offset and the presentation of the displaced stimulus improved people's ability to detect that the stimulus had been displaced and also their ability to judge the direction that it had been displaced, but only for displacements opposite to the direction of the saccade (backward displacements). A third experiment suggested that this improvement in the detection of backward displacements was due in part to subjects misremembering the saccade target location as being closer to the initial fixation point than it actually was immediately after the saccade but remembering its location more veridically 50 ms later. This has the effect of improving the detection of displacements as well as their direction of displacement, but preferentially for backwards vs. forward displacements.

1. Introduction

Objects in the world appear to maintain their positions in space even though their positions on the retinas change with every eye movement. This has often been presumed to occur via an accurate compensatory mechanism that takes eye position into account in order to maintain visual stability of objects across eye movements (Bridgeman, van der Heijden, & Velichkovsky, 1994). Evidence against this hypothesis has been provided by the finding that displacing a visual stimulus during a saccadic eye movement is often not noticed. For example, Mack (1970) changed the position of a visual target by varying amounts during a subject's eye movement and found that target displacements greater than 10% of the saccadic movement were usually detected, but displacements under 10% were rarely detected. Whipple and Wallach (1978) reported effects of similar magnitude, and Bridgeman, Hendry, and Stark (1975) reported that participants often failed to detect stimulus displacements of 33% of saccade amplitude. This failure to detect "abnormal" retinal image movements during saccades suggests that any compensatory mechanism accompanying a saccade must be rather inaccurate.

More recently, however, Deubel and colleagues (Deubel, Bridgeman, & Schneider, 1998; Deubel & Schneider, 1994; Deubel, Schneider, & Bridgeman, 1996) found that the presentation of a blank (empty screen) for 50–300 ms in the period between saccade target offset and the presentation of the displaced post-saccadic stimulus improved substantially the detection of the direction in which the stimulus had been displaced. They interpreted this as evidence that precise information about eye position and a highly accurate memory for the position of the pre-saccadic target are always available after a saccade, but this information is not used if other visual information (i.e., the post-saccadic target stimulus) is present when the eyes land. That is, if the post-saccadic stimulus is visible immediately after the saccade (as it is under normal, no-blank conditions) then it appears to have been present continuously and the perceptual system assumes that it did not move unless the displacement is large (cf., MacKay, 1973; Matin et al., 1982). When the post-saccadic stimulus is not visible, however, then stimulus continuity is no longer assumed and precise information about eye position and highly accurate information about the position of the pre-saccadic target can be used to compensate for changes in the retinal position of the saccade target and improve detection of its

* Corresponding author at: Department of Psychology, University of Illinois, 603 E. Daniel St., Champaign, IL 61820, United States.
E-mail address: irwin@illinois.edu (D.E. Irwin).

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displacement.

Using a procedure similar to that of Deubel and colleagues, Demeyer, De Graef, Wagemans, and Verfaillie (2010) and Tas, Moore, and Hollingworth (2012) also found that detection of the direction of stimulus displacement across a saccade was facilitated if a blank interval separated saccade onset and post-saccadic stimulus presentation. Using a different type of displacement judgment, however, Irwin and Robinson (2015) found that displacement detection per se was hurt by the presentation of a blank interval. In the Irwin and Robinson experiments participants had to report whether or not the saccade target was displaced at all, instead of having to report the direction in which it had moved. Irwin and Robinson found that detection was hurt by the presentation of a blank; in particular, blanking increased substantially the number of false alarms (i.e., participants reported that the saccade target had been displaced when in fact it had not). In sum, whereas several studies (e.g., Demeyer et al., 2010; Deubel et al., 1996, 1998; Tas et al., 2012) have shown that subjects are more accurate at detecting the direction in which a stimulus has been displaced when a blank interval separates saccade offset and stimulus onset, the results of Irwin and Robinson (2015) show that the presentation of a post-saccadic blank causes subjects to perceive stimulus displacement when in fact no displacement has occurred. This causes the false alarm rate to increase, thereby causing sensitivity to displacement to decrease in their experiments.

The results of Irwin and Robinson (2015) seem inconsistent with the notion that the pre-saccadic position of the saccade target is accurately stored in memory and that a precise eye position signal is available immediately after saccade onset but is overriden by the presence of the post-saccadic target stimulus. If such information were available, then it would seem that detection of stimulus displacements should also be improved rather than hurt by the presence of a blank interval because this information could be used to determine whether the stimulus had been displaced or not. The experiments that have found that blanking improves displacement detection have all used a task in which participants have to judge the direction in which a stimulus has been displaced, rather than whether a displacement has occurred at all, raising the possibility that blanking may improve the perception of motion direction rather than knowledge regarding the precise spatial position of a stimulus. For example, a small deviation in memory for the spatial position of the saccade target might be sufficient to trigger a displacement detection response when no displacement has actually occurred (causing a false alarm) while having little effect on judging the direction of motion. It is difficult to evaluate this, however, because the task used by Irwin and Robinson (2015) differed from that used by Deubel and others in several other ways in addition to the type of displacement judgment that was required. Thus, the purpose of the present study was to compare the effect of post-saccadic blanking on displacement direction performance (i.e., in which direction did the saccade target move) and displacement detection performance (i.e., did the saccade target move or not) in the same experimental paradigm.

2. Experiment 1

Two groups of subjects participated in Experiment 1 under blank and no-blank conditions. One group (the forward/backward group) judged in which direction a stimulus was displaced across a saccade, whereas the second group (the move/no-move group) judged whether a stimulus was displaced or not across a saccade.

2.1. Method

2.1.1. Participants

In total, 24 members (12 in each group) of the University of Illinois community participated in a single session that lasted approximately 50 min. They received $6 for their participation. Participants reported that they had normal or corrected to normal vision and they were not informed about the experimental hypotheses. All of the experiments reported in this paper were carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). The Institutional Review Board of the University of Illinois approved the research protocols. An informed consent form was signed by each participant before they took part in any experiment.

2.1.2. Stimuli and procedure

A 21-inch computer monitor (ViewSonic G810 CRT) was used for stimulus presentation. The refresh rate was 85 Hz. An Eyelink II video-based eyetracker (SR Research Ltd., Mississauga, Ontario, Canada) was used to record eye position. This system has a temporal resolution of 500 Hz, a spatial resolution of 0.1°, and a pupil-size resolution of 0.1% of pupil diameter. The participants sat with their heads in a chinrest 49 cm from the display. The stimuli were black and were presented on a white background (luminance = 86.3 cd/m^2). A Microsoft Sidewinder digital game controller connected to the eye-tracking computer collected participants' manual responses.

The eye tracker was calibrated before each block of experimental trials by having participants fixate the edges and center of the display monitor. The sequence of events on each trial was based on that used in Experiment 2 of Deubel et al. (1996). Participants fixated a drift correction dot subtending 0.6° at the beginning of each trial and pressed a button on the game controller to initiate each trial. A blank screen was then presented for 506 ms, followed by the presentation of a cross (subtending 0.8° by 0.8°) at the display's center. A 506 ms delay ensued before this cross was erased and another cross (subtending 0.8° by 0.8°) was presented to the left or to the right, either 6° or 8° away. Subjects made a saccade to this peripheral cross, which was removed from the display upon detection of saccade onset. The cross was then presented again, either during the saccade (no-blank condition) so that the cross was present on the screen when the saccade ended, or following a 300 ms delay (blank condition), long after the saccade had ended and while the subject was fixating the blank screen. This cross was displaced with respect to its original position (or not) by some amount (−2°, −1°, 0°, 1°, or 2°), where negative displacements denote backwards displacements (i.e., in the opposite direction from the saccade), positive displacements denote forward displacements (i.e., in the same direction as the saccade), and 0 represents no displacement. One group of subjects (the forward/backward group) judged whether the cross had been displaced in a forward or backward direction, whereas a second group of subjects (the move/no-move group) judged whether the cross had been presented in its original position or in a new, displaced, position. Participants made their responses by pressing buttons (arrayed vertically) on the game controller. Participants received no feedback regarding the accuracy of their responses.

Each participant completed 520 trials. Saccade direction (left vs. right), saccade distance (6° or 8°), displacement distance (−2°, −1°, 0°, 1°, or 2), and blank condition (0 or 300 ms blank) were counterbalanced but across trials the conditions appeared in a random sequence. Participants received a break and were recalibrated after every 52 trials.

2.2. Results

Trials were not included in the analyses if the experiment program failed to detect a saccade, if the display change was not completed during the saccade, or if the participant failed to follow instructions. Table 1 presents information about saccade latencies, amplitudes, and durations as a function of saccade distance and saccade direction for both groups of subjects. Saccade distance and saccade direction were varied solely to create uncertainty about the initial position of the saccade target and were not considered further in the remaining analyses. The results for the forward/backward group will be discussed first, followed by the results for the move/no-move group.

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