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The effect of different brightness conditions on visually and memory guided saccades

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ABSTRACT

It is commonly assumed that saccades in the dark are slower than saccades in a lit room. Early studies that investigated this issue using electrooculography (EOG) often compared memory guided saccades in darkness to visually guided saccades in an illuminated room. However, later studies showed that memory guided saccades are generally slower than visually guided saccades. Research on this topic is further complicated by the fact that the different existing eyetracking methods do not necessarily lead to consistent measurements. In the present study, we independently manipulated task (memory guided/visually guided) and screen brightness (dark, medium and light) in an otherwise completely dark room, and measured the peak velocity and the duration of the participant's saccades using a popular pupil-cornea reflection (p-cr) eyetracker (Eyelink 1000). Based on a critical reading of the literature, including a recent study using cornea-reflection (cr) eye tracking, we did not expect any velocity or duration differences between the three brightness conditions. We found that memory guided saccades were generally slower than visually guided saccades. In both tasks, eye movements on a medium and light background were equally fast and had similar durations. However, saccades on the dark background were slower and had shorter durations, even after we corrected for the effect of pupil size changes. This means that this is most likely an artifact of current pupil-based eye tracking. We conclude that the common assumption that saccades in the dark are slower than in the light is probably not true, however pupil-based eyetrackers tend to underestimate the peak velocity of saccades on very dark backgrounds, creating the impression that this might be the case.

1. Introduction

Are saccades in the dark slower than saccades in an illuminated room? According to the literature on this topic, this question has been answered a long time ago and has since appeared in at least one textbook (Craighead & Nemeroff, 2002) and Scholarpedia (Findlay & Walker, 2012): The peak velocities of saccades made in the dark seem to be slower than those of saccades made in a lit room. Craighead and Nemeroff, for example, state that "saccades are about 10% slower in complete darkness than in the light" (Craighead & Nemeroff, 2002, p. 1431). They back up their statement by citing three studies: Bahill, Clark, and Stark (1975), Becker and Fuchs (1969), and Henriksson, Pyykkö, Schalén, and Wennmo, 1980. However, the results of these studies do not allow this conclusion, as we will outline below. Findlay and Walker (2012) even consider this finding general knowledge and do not provide any citations.

Becker and Fuchs (1969) asked their participants to make horizontal eye movements while measuring their electrooculogram (EOG). Participants first repeatedly made saccades between two dim light spots. After they had learned the correct magnitude, the light was switched off and they were asked to continue with the eye movements. Becker and Fuchs (1969) compared the peak velocities and the durations of these saccades to saccades made in a well illuminated room to visible targets. They found that peak velocities were lower and durations were longer in the dark. In a control condition they covered each eye of the participants with half of a ping pong ball while they made saccades in a well illuminated room. They did not find any differences between saccades of the control condition and the dark condition.

Bahill et al. (1975) also used EOG to measure the amplitude, peak velocity and duration of their participants' saccades. They found that peak velocity and duration both increase with increasing amplitude. They were the first to use the term *main sequence* for this relation. They did not study saccades in the dark.

Henriksson et al. (1980) presented light diodes placed at different eccentricities. The complete experiment was conducted in the dark. First, participants made saccades to the light diodes. Then, the diodes

Abbreviations: VGS, visually guided saccades; MGS, memory guided saccades; EOG, electrooculogram; C_M, Michaelson contrast

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were switched off and the participants continued to execute saccades to the remembered locations. Measuring the eye movements with EOG, they found that peak velocities were lower in darkness than with switched on light diodes. Thus, they compared memory guided (MGS) to visually guided saccades (VGS). It is known that memory guided saccades are moderately slower than their visually guided counterparts (Gnadt, Bracewell, & Andersen, 1991; Opris, Barborica, & Ferrera, 2003; Shaikh et al., 2010; Smit, Van Gisbergen, & Cools, 1987).

To summarize, only the study by Becker and Fuchs (1969) includes a valid comparison between saccades in the dark and saccades in a lit room, the comparison of saccades in a lit room with the eyes covered by ping pong ball halves to saccades in the dark. They did not find any differences between both conditions.

The issue is further complicated by the fact that different eye tracking techniques do not necessarily lead to consistent measurements. Hooge, Holmqvist, and Nyström (2016), for example, found that pupil-cornea reflection (p-cr) eye tracking systems systematically overestimate the saccadic peak velocity and thus may not be suited to investigate such details.

In a recent study, Nyström, Hooge, and Andersson (2016) used an SMI Hi-speed 1250 pupil based video eye-tracker to investigate the effect of different pupil sizes on the peak saccadic velocity by manipulating screen luminance. This eyetracker can track either p-cr or only one of these measures. They asked four healthy observers to make repeated horizontal saccades to targets at two different eccentricities on seven levels of background illumination. They found the lowest peak velocities for the smallest pupil size/brightest background. They also found that peak velocity increased with increasing pupil size, with the exception of the largest pupil size/dimmest background, which lead to lower peak velocities. Crucially, when they only analysed the corneal reflection signal, they found that peak velocity did not change with increasing pupil size/illumination.

Are saccades in the dark slower than saccades in the light? The control condition by Becker and Fuchs (1969) and the cornea reflection results of Nystrom et al. (2016) suggest that this does not seem to be the case. In the present study, we independently manipulated task and illumination. We asked participants to make visually guided, as well as memory guided saccades to stimuli on three different background luminances, while keeping the stimulus-background contrast constant. We used an Eyelink 1000 eye tracker, a p-cr tracking system that is frequently used in eye movement research. In the following sections, we first present the results as they were obtained by the p-cr eye tracker. Then, we present the results after "regressing out" the variance in the peak velocities explained by the pupil size changes. According to the previous results by Becker and Fuchs and Nyström et al. we should not find any velocity differences between our three brightness conditions.

2. Methods

2.1. Apparatus and environment

The experiment was conducted in the Eyetracker Laboratory of the Otto-von-Guericke-University in Magdeburg, Germany. The lighting conditions in the laboratory were well controlled. The laboratory is located in the basement of the institute of psychology on the main campus. During the procedure all the windows were closed with wooden casements, isolating the room well in sound and light. The monitor was the only perceptible light source for the participants. There was a partition wall between the experimenter and the participant in order to not disturb them and to keep any influences at a minimum.

The experiment was conducted with an Eyelink® 1000 eye tracker (SR research) with a temporal resolution of 1000 Hz. The eyetracker corrected for the effect of pupil size on pupil position, which occurs when the camera looks at the eye not from straight on, by using the built-in function pupil_crosstalk_fixup (see entry in defaults.ini). The experiment was run on a MacBook® (Apple Inc.) laptop computer (2 GHz CPU, 2 GB RAM) using the Psychophysics toolbox version 3 (Brainard, 1997) for MATLAB® (Mathworks, Natick, MA, v. R2008a). Participants positioned their heads on a chin rest for better fixation and looked at a BenQ LCD-Monitor XL 2410T with a 24 inch display (52 cm × 29,5 cm/34° × 19.7°), presenting the stimuli at 60 Hz. The resolution of the monitor was 1920 × 1080 pixels. The distance between the monitor and the chin rest was 85 cm.

2.2. Participants

In total 26 students and non-student volunteers with a mean age of 25.6 years (range 18–47) participated in the experiment. 16 women and 10 men with normal or corrected to normal vision were tested. They all signed informed consent before the start of the experiment. All participants reported good health and no fatigue. All recordings were conducted on the left eyes of the participants. The experiment was conducted in compliance with the Declaration of Helsinki.

2.3. Procedure and design

The experiment consisted of two tasks (visually and memory guided saccades, see description below) with three conditions each. The conditions consisted of three different illuminated gray backgrounds. A dark, a medium and a light one. The exact brightness values of the conditions are listed in Table 1. The conditions were presented in blocks of 200 trials each. Before each block participants adapted for 5 min to the new brightness condition. The gain in sensitivity for seeing in the darkness is greatest during the first 5 min of adaptation (Schandry, 2003). A full adaption would require 20 min, which wouldn't be reasonable for the participants as it would extend the experiment excessively.

To calculate the gray values such that they match with the required luminances for the different brightness conditions, we used a Konika Minolta Chroma Meter CS-200 and measured the luminance of the LCD monitor for all three backgrounds on 5 positions (every corner and the center). The mean values were calculated and used to determine the required gray values of the stimuli. The gray values of the dot targets were chosen such that their contrasts to the background stayed the same across conditions ($C_M = 0.5863$). The eye tracker was calibrated and validated after each adaption phase with a 13 point calibration in the colors and illumination of the following condition.

We measured each participant's pupil size for all tasks and conditions, using the pupil size output given by the Eyetracker. These sizes were averaged and tested with within-subject paired t-tests, whether they were significantly different from the pupil sizes in the medium brightness condition, which were normalized to a value of 1. The results are listed in Table 2. The pupil sizes in the dark and light brightness conditions were significantly different from those in the medium brightness condition, which confirms that the brightness conditions were indeed different for the individual participants. We additionally converted the arbitrary area units for pupil size to mm. Both area units and mm values are shown in Table 3.

2.4. Visually guided saccades

To avoid a confusion of the participants, the three conditions of each task were tested after each other, but in random order. Half of the

Table 1
Specifications of brightness conditions.

Background	RGB Back.	$\bar{X}$ Lum. Back.	RGB target	$\bar{X}$ Lum. target
Light	240 240 240	68,33 cd/m^2	95 95 95	12,78 cd/m^2
Medium	100 100 100	14,93 cd/m^2	43 43 43	3,89 cd/m^2
Dark	20 20 20	1,07 cd/m^2	0 0 0	0,28 cd/m^2