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What is the best fixation target? The effect of target shape on stability of fixational eye movements

L. Thaler [a,b,*], A.C. Schütz [c], M.A. Goodale [b,d], K.R. Gegenfurtner [c]

[a] Department of Psychology, Durham University, United Kingdom
[b] Department of Psychology, The University of Western Ontario, Canada
[c] Department of Psychology, Giessen University, Germany
[d] The Brain and Mind Institute, The University of Western Ontario, Canada

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ABSTRACT

People can direct their gaze at a visual target for extended periods of time. Yet, even during fixation the eyes make small, involuntary movements (e.g. tremor, drift, and microsaccades). This can be a problem during experiments that require stable fixation. The shape of a fixation target can be easily manipulated in the context of many experimental paradigms. Thus, from a purely methodological point of view, it would be good to know if there was a particular shape of a fixation target that minimizes involuntary eye movements during fixation, because this shape could then be used in experiments that require stable fixation. Based on this methodological motivation, the current experiments tested if the shape of a fixation target can be used to reduce eye movements during fixation. In two separate experiments subjects directed their gaze at a fixation target for 17 s on each trial. The shape of the fixation target varied from trial to trial and was drawn from a set of seven shapes, the use of which has been frequently reported in the literature. To determine stability of fixation we computed spatial dispersion and microsaccade rate. We found that only a target shape which looks like a combination of bulls eye and cross hair resulted in combined low dispersion and microsaccade rate. We recommend the combination of bulls eye and cross hair as fixation target shape for experiments that require stable fixation.

1. Introduction

When people fixate a visual target, they intend to keep their gaze still. Nonetheless, the eyes make small, involuntary movements (e.g. tremor, drift, microsaccades) (for reviews see for example Martinez-Conde, Macknik, & Hubel, 2004; Martinez-Conde et al., 2009; Rolfs, 2009). This can be a problem during experiments that require participants to keep their gaze stable for extended periods of time. For example, eye movements during fixation shift the location of a stimulus on the retina, which introduces noise into retinal receptive field measurements acquired with neurophysiological recording techniques, multifocal Electroretinograms (Sutter & Tran, 1992; Zhang et al., 2008), or high-resolution fMRI (e.g. Schira et al., 2009). In addition, the planning and execution of eye movements during fixation results in neural and muscular activity, as well as physical motion of the eye ball, all of which affects measurements that are based on electric and/or magnetic field strength, such as EEG, MEG and fMRI (Dimigen et al., 2009; Tse, Baumgartner, & Greenlee, 2010; Zhang et al., 2008). Thus, from a methodological point of view it would be good to minimize involuntary eye movements during fixation for experiments that require stable fixation.

Previous research has shown that fixational eye movements are affected by variables, such as attention to the process of ocular fixation itself (Steinman et al., 1967), selective attention to aspects of the visual display (e.g. Engbert & Kliegl, 2003a; Hafed & Clark, 2002), precision requirements of the response (Ko, Poletti, & Rucci, 2010), presence of visual 'distracters' (Otero-Millan et al., 2008), changes in the visual display (Engbert & Kliegl, 2003a; Sinn & Engbert, 2011), or the experimental viewing condition (i.e. free viewing vs. fixation) (Ko, Poletti, & Rucci, 2010; Otero-Millan et al., 2008). None of these variables are easily manipulated within the context of an experimental paradigm. Properties of the fixation target that would perhaps be easier to manipulate, such as blur, color, luminance and/or luminance contrast, have no effect on fixational eye movements unless they render the target barely visible, in which case fixation is bad (Boyce, 1967; Steinman, 1965; Ukwade & Bedell, 1993). Finally, it has been shown that changes in the size of a fixation target result in changes in both dispersion (drift) and microsaccade rate (Steinman, 1965). However, even though it is the case that target size has an effect on fixational eye movements, it is not the case that a specific target size would

* Corresponding author at: Department of Psychology, Durham University, Science Site, South Road, Durham DH1 3LE, United Kingdom.
E-mail address: lore.thaler@durham.ac.uk (L. Thaler).

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generally reduce both drift and microsaccades during fixation. The shape of a fixation target can be easily manipulated in the context of many experimental paradigms. Therefore, the shape of a fixation target might be a good variable to manipulate in order to reduce involuntary eye movements during fixation.

To survey which fixation target shapes researchers typically use in their research, i.e. if there is already some sort of 'gold-standard' in place, we surveyed the shape of fixation targets that were used in experiments published in Journal of Vision. We included articles from regular and special issues of Journal of Vision published between 2001 (volume 1, issue 1) and 2009 (volume 9, issue 1), we excluded issues consisting of conference abstracts. For the purpose of the survey, the article text (including footnotes, captions, figures and tables) was searched for the letter combination 'fixa'. If the search produced a hit, the article was manually searched to determine if the research had used a fixation target. If so, the article was manually searched for the most detailed verbal description of the fixation target's shape. Experiments that involved fixation, but did not mention or describe a visual target, were not included in the survey. If an article contained multiple experiments and used different fixation target shapes for each experiment, each description was counted separately. This resulted in a sample of 500 fixation target shapes. The results of the survey are shown in Table 1. Two things are evident. First, we found a large number of descriptions such as 'target', 'spot', 'point' or 'mark', without any reference to a specific shape and/or size. Second, those descriptions that are more specific indicate that a wide variety of fixation target shapes and sizes are in use, even though there appears to be a preference towards circular target shapes or crosses.

In summary, the shape of a fixation target can be easily manipulated in the context of many experimental paradigms, and there is currently no 'gold-standard' for a specific target shape in the literature. At the same time, stable fixation is required for many behavioral and neuroimaging experiments (e.g. Electroretinograms, EEG, MEG, fMRI). Thus, from a purely methodological point of view, it would be good to know if there was a particular shape of a fixation target that minimizes involuntary eye movements during fixation, because that target shape could then be used in experiments that require stable fixation. Based on this methodological motivation, the current experiments tested if the shape of a fixation target can be used to reduce involuntary eye movements during fixation.

2. Methods and materials

2.1. Experiment 1

2.1.1. Ethics statement

Two subjects performed the experiment at the University of Western Ontario, Canada, and 10 subjects performed the experiment at Giessen University, Germany. All testing procedures were approved by the ethics board at the University of Western Ontario, and by the ethics board at Giessen University, respectively. Participants gave written informed consent prior to testing. Subjects (except the first author) were paid 10 CAD, or 8 Euro, respectively, for participation.

2.1.2. Subjects

Twelve subjects (incl. the first author) participated in the experiment. Subjects had normal or corrected to normal vision.

2.1.3. Apparatus and eye-movement recording

At the University of Western Ontario visual stimuli were presented on a 19 in. LCD monitor (Dell Ultrasharp) with an ATI Radeon HD 2400XT graphics card at a temporal resolution of 75 Hz and a spatial resolution of 1280(H) $\times$ 1024(V) pixel. The active display area subtended 37.5(H) $\times$ 30(V) cm, and the display was positioned at a distance of 46 cm from the observer. At Giessen University, visual stimuli were presented on a 21in CRT monitor (ELO Touchscreen) with an Nvidia Quadro NVS 285 graphics card at a temporal resolution of 100 Hz and a spatial resolution of 1280(H) $\times$ 1024(V) pixel. The active display area subtended 37(H) $\times$ 29.6(V) cm, and the display was positioned at a distance of 47 cm from the observer. Eye position signals were recorded by a separate PC with a head-mounted, video-based eye tracker (EyeLink II; SR Research Ltd., Osgoode, Ontario, Canada) and were sampled at 250 Hz. At the University of Western Ontario we used 'pupil with corneal reflex' mode to record eye position signals for both subjects. At Giessen University, we used 'pupil with corneal reflex' mode for one subject, 'pupil only' mode for five subjects, and for the remaining four subjects we used 'pupil only' mode in one session, and 'pupil with corneal reflex' mode in the other. The system was calibrated at the beginning of each experimental session by instructing the observer to fixate single dots that appeared successively at nine different positions on the monitor. Based on the results of this calibration, the better eye was chosen automatically by the system, and eye position was recorded from this eye. Observers were seated with their heads stabilized with a chin rest. They viewed the display binocularly through natural pupils. Experimental software was written using the Eyelink SDK, Windows API, OpenGL and C/C++ programming language.

2.1.4. Stimuli

Our survey of fixation target shapes showed that experiments that require stable fixation commonly use circle and cross shapes, as well as their combinations, as fixation target shapes (Table 1). Thus, we decided to use circles and crosses and their combinations as target shapes in our experiment. Fig. 1 illustrates the seven different targets shapes that were used. In addition, we included a small and a large circle shape (target shape A and B) as control conditions. Previous research has shown that shape A elicits less dispersion, but a higher number of microsaccades as compared to shape B (Steinman, 1965). Thus, if our experimental setup is sensitive enough to measure variations in eye movements during fixation, we would expect to see a negative relationship between these two dependent measures for target shape A and B. All stimuli were shown in front of a homogeneously gray background. Stimuli were shown both black-on-gray (illustrated in Fig. 1, top panel), as well as white-on-gray. Code for drawing the ABC target using Matlab (The Mathworks, Natick, MA, USA) and Psychtoolbox (Brainard, 1997) is given in Appendix A.

2.1.5. Task and procedure

Subjects were instructed to keep their gaze directed at the center of the fixation target and as stable as possible throughout a trial (trial duration 17 s). Before the onset of a trial the subjects saw the target shape colored in red. Once the subject was ready, they pressed a button with their right index finger to start a trial. Once they pressed the button, the target shape changed from red to black. After 10 s, the target changed from black to white. Then, after another 7 s the target disappeared. The screen remained gray for 3 s, before the next target would appear. The combination of luminance change and 3-s 'blank' minimized the presence of afterimages. Two subjects each performed four separate sessions on four separate days. In each session, each of the seven target shapes was shown nine times, so that each session contained 63 trials total. The other 10 subjects each performed two separate sessions on two separate days. In each session, each of the seven target shapes was shown twelve times, so that each session contained 84 trials total. For all subjects and sessions presentation of target shapes within each session was block-randomized in order to balance presentation order over the course of the experiment. Eye movement