Perceptual consequences of retinal stabilization with a high-frequency LCD display

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Abstract

Several recent studies have shown decreased sensitivity when stimuli are immobilized on the retina, a procedure known as retinal stabilization. Because of the technical challenges inherent in this procedure, studies have either used fast-phosphor CRT displays or directly updated the stimulus on the retina by means of adaptive optics scanning laser ophthalmoscopes. Both display systems provide brief pulses to the retina, raising the question of whether this flicker contributed to perceptual effects. Here we report the results of retinal stabilization experiments conducted with LCD monitors at high refresh rates. Results replicate previous findings of high-frequency impairments under retinal stabilization. These data provide further support for a functional role of small eye movements during visual fixation.

Results and Discussion

Humans are not aware that their eyes are always in motion, even when attempting to maintain steady gaze. In the brief periods of fixation in between rapid gaze shifts (saccades) a small, jittery motion continually shifts the image on the retina over dozens of photoreceptors (1). It has long been proposed that the fixational motion of the eye is helpful for visual processing (2; 3; 4; 5). Experiments with retinal stabilization, a condition in which the stimulus moves together with the eye to remain immobile on the retina, have provided support to this hypothesis. When the retinal motion caused by ocular drift is eliminated, visual sensitivity to high spatial frequency stimuli is selectively impaired (6; 7; 8; 9) in keeping with the information provided by the luminance modulations delivered by ocular drifts (6). Humans also

control eye drifts according to the task in ways that are consistent with use of the resulting luminance modulations (9; 10).

While this growing body of evidence provides strong support to the proposal that fixational drift is one of the elements of an active visuomotor strategy for encoding visual information (11; 8), most stabilization experiments were achieved with systems that provides flickering stimulation to the retina. Although capabale of relatively high frame rates, Cathode Ray Tube (CRT) displays sequentially render the image as the electron beam moves from the top to the bottom of the screen. Similarly, adaptive optics scanning laser ophthalmoscopes use lasers to sequentially render the stimulus on the retina achieving substantially lower refresh rates (7). It is unknown whether the sequential turning on and off of the stimulus on the retina carries perceptual consequences.

To investigate this question, here we repeated classical experiments of retinal stabilization using a liquid-crystal display (LCD) monitor at very high refresh rate (360 Hz). Since LCD monitors have constant back-light and refresh pixels only when the image changes, this type of display avoids inter-frame blank periods. Furthermore, the pressure for fast gaming displays has led to LCD with remarkably high refresh rates, enabling even higher accuracy of retinal stabilization.

In our experiment, repeating a classical protocol (6), subjects (N = 4) were asked to report the orientation of a tilted high spatial frequency grating (16 cycles per degree, $\pm 45°$) during normal fixation. Stimuli were presented in two conditions: they were either maintained stationary on the monitor as in normal viewing (Fig. 1A top) or moved in real-time, under computer control, following the eye movements of the observers (stabilization condition, Fig. 1A bottom). In both conditions, eye movements were continually recorded by means of a high-resolution dual Purkinje Image eye-tracker (12), a system that provides arcminute resolution with 1 ms delay.

The orientation of the stimulus varied randomly across trials. Each trial started with the subjects fixating for 500 ms on a marker (a $10'$ dot) at the center of a uniform gray field. The stimulus then appeared gradually with linearly increasing contrast over an initial period (800 ms), which was followed by 500 ms exposure at the plateau contrast. A large-field maximum contrast noise mask ended the trial, prompting subjects to report the perceived orientation of the grating by pressing one of two buttons on a joypad. The contrast of the grating varied adaptively across trials following the Parametric Estimation by Sequential Testing (PEST) procedure (13) aiming for $\sim$75% correct discrimination for each individual.

In this study we only considered the trials in which the eye moved exclusively because of ocular drift. All trials containing blinks, saccades or microsaccades during stimulus presentation were discarded from data analysis. Contrast thresholds were estimated by using all tested contrast levels and modeling psychometric functions with cumulative log-normal curves via the maximum likelihood procedure proposed by [14]. Contrast sensitivity was defined as the inverse of the estimated contrast threshold.

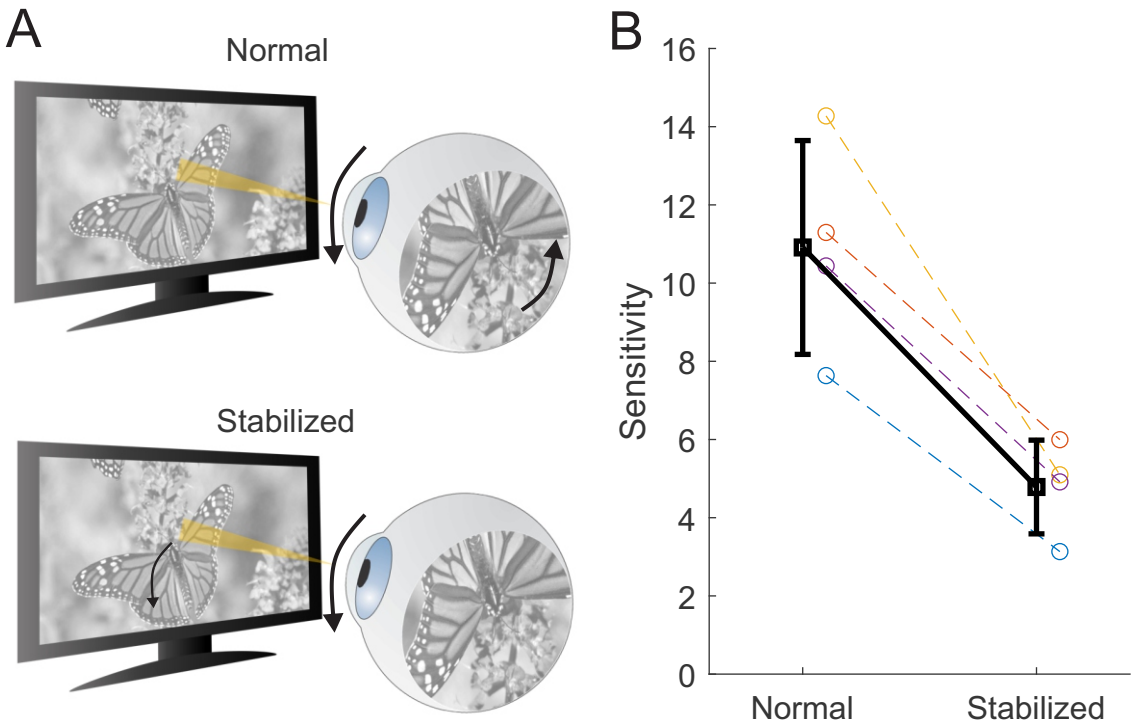

Figure 1: **Influence of retinal motion on visual sensitivity. (A)** In normal viewing condition, eye movements cause retinal image motion. In stabilization condition, stimuli move with the eye and are immobilized on the retina. **(B)** Stabilizing the stimulus on the retina impairs contrast sensitivity for all subjects.

Results show that contrast sensitivity is greatly impaired under retinal stabilization ($p = 0.01$, Fig. 1B). On average across subjects, sensitivity decreases by 56%, an impairment consistent with previous observations obtained using CRT displays at lower refresh rates. This effect was highly consistent across observers, with all of them exhibiting a similar impairment under retinal stabilization.

These results show that the impairments measured under retinal stabilization are robust with respect to the type of display and rendering frequency. Perception of high spatial frequency patterns is impaired in the absence of the visual input changes normally resulting from eye movements. Thus, luminance modulations from small eye movements appear to play an important role in visual encoding.

Methods

Participants

Four subjects took part in this study. All subjects were emmetropic and were compensated for their participation. Informed consent was obtained from all participants. The study followed the procedures approved by the University of Rochester Institutional Review Board.

Stimuli and Apparatus

Stimuli consisted of large-field sinusoidal gratings tilted by $\pm 45°$ relative to the vertical axis and displayed over a uniform background (luminance 7 cd/m^2; field size: 58° by 50°). The grating was 16 cycles/deg and foveal vision was eliminated by an artificial scotoma to minimize the possibility that eye movements would change between conditions. The artificial scotoma was a circular (1° diameter) opaque gray region at background luminance with a surrounding 0.5° annulus of tapered transparency, which remained centered on the line of sight as the eyes moved normally during fixation.

Stimuli were displayed on an LCD monitor (ASUS259QN) in a dimly illuminated room. Stimuli were viewed monocularly with the right eye while the left eye was patched. The subject's head was immobilized by a dental imprint bite-bar and a headrest to maintain a fixed distance of 123 cm from the monitor. Movements of the viewing eye were measured by custom digital Dual Purkinje Image (DPI) eye-trackers (12). Stimuli were rendered using EyeRIS, a system for gaze-contingent display control that enables real-time synchronization between oculomotor measurements and the updating of the image on the monitor (15).

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