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Research article

Extrafoveally applied flashing light affects contrast thresholds of achromatic and S-cone isolating, but not L-M cone modulated stimuli

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ABSTRACT

Flashing light stimulation is often used to investigate the visual system. However, the magnitude of the effect of this stimulus on the various subcortical pathways is not well investigated. The signals of conscious vision are conveyed by the magnocellular, parvocellular and koniocellular pathways. Parvocellular and koniocellular pathways (or more precisely, the L-M opponent and S-cone isolating channels) can be accessed by isoluminant red-green (L-M) and S-cone isolating stimuli, respectively. The main goal of the present study was to explore how costimulation with strong white extrafoveal light flashes alters the perception of stimuli specific to these pathways. Eleven healthy volunteers with negative neurological and ophthalmological history were enrolled for the study. Isoluminance of L-M and S-cone isolating sine-wave gratings was set individually, using the minimum motion procedure. The contrast thresholds for these stimuli as well as for achromatic gratings were determined by an adaptive staircase procedure where subjects had to indicate the orientation (horizontal, oblique or vertical) of the gratings. Thresholds were then determined again while a strong white peripheral light flash was presented 50 ms before each trial. Peripheral light flashes significantly ($p < 0.05$) increased the contrast thresholds of the achromatic and S-cone isolating stimuli. The threshold elevation was especially marked in case of the achromatic stimuli. However, the contrast threshold for the L-M stimuli was not significantly influenced by the light flashes. We conclude that extrafoveally applied light flashes influence predominantly the perception of achromatic stimuli.

1. Introduction

According to our current knowledge, conscious vision utilizes the signals of three subcortical pathways, the magnocellular (MC), parvocellular (PC) and koniocellular (KC) pathways [1]. Visual information of high spatial and low temporal frequencies, as well as color opponent signals from red (L-) and green (M-) cones are conveyed by the PC pathway, while the MC pathway is usually associated with the processing of dynamic stimuli of high temporal and low spatial frequencies [2]. Furthermore, instead of color contrast, the MC pathway is sensitive to luminance contrast [3]. The KC pathway is more heterogeneous, but its importance in forwarding blue (S-) vs. yellow (L + M) cone opponent signals is firmly established [4,5].

To investigate these pathways separately, pathway-specific stimuli are necessary. Due to the inherent heterogeneity of neuronal response preferences, it is essentially not possible to devise a stimulus that elicits responses in all neurons of one pathway without overlap with others. However, the detection of some stimuli can be mainly ascribed to a subset of neurons in one of the pathways. Thus, the application of isoluminant red-green and S-cone isolating stimuli, respectively, is adequate to stimulate the color-opponent neurons in the PC and KC pathways, respectively [4,5]. An input from S-cones to PC and MC neurons can be demonstrated, but its extent is negligible [6,7].

Magnocellular neurons respond most to achromatic stimuli although under certain conditions [8], they can utilize red-green isoluminant contrast. A number of other methods have been devised to study the functionality of the MC pathway, such as coherent motion detection [9,10], contrast sensitivity [1,11], the Ternus-test (phantom contours) [12,13] and extrafoveal luminance stimulation as a means of suppression [14–18].

Light flashes are among the most commonly used stimuli to test the function of different parts of the visual system from the retina[19] to the visual cortex[20]. Light flashes are also known to suppress the detection of other visual stimuli, although the extent of suppression on the different visual pathways is still unclear. Regarding the MC and PC pathways the results generally point in two directions. There is

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evidence that light flashes, when presented extrafoveally, suppress MC function [17,18] at the retinal level. On the other hand, Schoenfeld et al. [21] reported that flashing light suppresses the detection of static visual stimuli by silencing the primary visual cortex (V1). Similarly, extrafoveal flashing light significantly altered the coherence detection threshold for static Glass pattern stimuli, while it did not influence the coherent motion detection threshold [10]. In the latter study, however, no conclusion could be drawn regarding the role of MC and PC pathways in the observed effect, especially because only achromatic stimuli were applied. Beside these conflicting findings, there is no information on how if in any way light flashes influence KC- mediated functions.

Based on such premises, we sought to investigate the effect of extrafoveally applied light flashes on the contrast detection thresholds of achromatic, L-M- and S-cone modulated stimuli in human psychophysical experiments.

2. Materials, methods

2.1. Participants

Seventeen healthy adult volunteers participated in the study (mean age: 29 years, 15 male, 2 female). Six of them took part in a testing session focusing only on the color stimuli. All participants had negative neurological status, seven were emmetropes and ten had vision corrected to 5/5. The study design conformed to the tenets of the Declaration of Helsinki in all respects, and it was approved by the Medical Ethics Committee of the University of Szeged, Hungary. Before the testing, the subjects were informed about the background and goals of the study, as well as about the procedures involved. This information was provided both in oral and written form. All volunteers signed an informed consent form.

2.2. Experimental apparatus

All stimuli were generated using the Expo software (Peter Lennie, University of Rochester, NY, USA). For stimulus presentation, a color-calibrated CRT monitor (refresh rate 96 Hz) was used. The monitor was turned on at least 60 min before the measurements began. Subjects were seated at a 57 cm distance from the stimulating apparatus in an otherwise darkened room (background luminance: 0.5 cd/m^2) with their head fixed in an ophthalmic head-rest, so that all stimuli appeared at eye level.

2.3. Testing

Testing consisted of three phases for each participant. First, the individual isoluminant points of the participant along the S- and the L-M axes of the McLeod-Boynton-Derrington-Krauskopf-Lennie color space were determined in order to minimalize luminance contribution to these stimuli. The isoluminant point was determined using the minimum motion technique, which has been shown to provide equivalent results to other criteria of isoluminance (such as minimum flicker or minimum distinct border) [22]. Using keys on a computer keyboard, each subject adjusted the relative luminance of two colors that were nominally isoluminant so that apparent motion was minimized.

In the second phase, the contrast threshold of the subject was measured using Gabor patches (sine-wave gratings with a Gaussian envelope) of three different color compositions (Fig. 1): achromatic (black/white) gratings and two isoluminant chromatic gratings ("red-green" and S-cone isolating). For each contrast level (Michelson-contrast), L- and M-cones were modulated in the same phase for the achromatic and in the opposite phase for the L-M stimulus. For the S-cone isolating stimulus, only S-cone contrast was modulated. The patches were presented on an isoluminant gray background of 42 cd/m^2 luminance. The Gaussian envelope of the patches had a standard deviation of 0.6 deg and a spatial frequency of 1 cycle/degree.

The task for the participants was to indicate the orientation of the stimuli (horizontal/vertical/oblique) by pressing one of three different keys on a keyboard. The orientation for each trial was selected randomly by the computer. Stimulus duration was set to 50 ms. Contrast detection thresholds for the three different stimuli were determined by an adaptive staircase procedure starting at a contrast of 0.5. Depending on the correctness of the responses, the software increased or decreased the contrast of the grating as described by Levitt [23] with a minimum step of 0.0025 contrast. The contrast levels were recorded for 60 trials for all conditions. The mean of the contrast levels during the last 20 iterations was taken as the contrast threshold for each condition.

In the third phase, contrast thresholds were determined again by the same procedure, except that strong white light flashes were presented throughout the stimulation, 50 ms before the presentation of each stimulus. The light flashes were generated with a 45 W Omnilux flashtube (No. 85010145, luminance: 480.3 cd/m^2, flash duration 0.1 ms, diameter: 20 cm) mounted directly over the stimulation monitor. The distance between the center of the stimuli and the center of the flashtube was 16 deg. The test gratings were presented 50 ms after each flash in order to minimize the impact of photoreceptor adaptation. The surfaces that might reflect the light flashes were minimized in the testing area.

Presentation order of the conditions varied from participant to participant. At least 5 min rest was allowed between blocks to minimize the effect of one block on another. A block of practice trials (60 trials) was applied at the beginning of the testing with light flashes, to allow participants to get used to the simultaneous flash stimulation.

Statistical analysis was performed in Statistica for Windows 12.0 (StatSoft, USA).

Sample size calculation was performed in G*Power 3.1 [24], in order to check the validity of the significant results. Based on the means and standard deviations of the different groups, the effect size and required sample size were determined. For the achromatic stimuli, the effect size and sample size was found to be 1.769 and 6 respectively. In case of the S-cone isolating stimuli the effect size was 1.104, while the required sample size was 11.

3. Results

The contrast thresholds to the achromatic, red-green (L-M) and S-cone isolating stimuli (with and without extrafoveal light flashes) are shown in Table 1.

For the achromatic stimuli, the mean of the thresholds without light flashes was 0.026 (median: 0.026, SD: 0.007). With light flashes, the mean of thresholds increased to 0.049 (median: 0.049, SD: 0.015). For S-cone isolating stimuli, the mean of contrast thresholds was 0.269 (median: 0.249, SD: 0.08), and it increased to 0.366 (median: 0.373; SD: 0.094) when the stimuli were presented following a light flash. The mean of color contrast thresholds for red-green (L-M) stimuli was 0.209 (median: 0.202, SD: 0.05). Applying flashing light before stimulus presentation resulted in a mean of 0.228 (median: 0.214; SD: 0.043).

A comparison of achromatic, red-green and S-cone isolating contrast thresholds determined with and without light flash is shown in Fig. 2. As the distribution of the contrast thresholds did not satisfy the criterion of normality (Shapiro-Wilk, $p < 0.05$), the Wilcoxon matched pairs test was used for the comparisons. Both in the case of the achromatic ($p < 0.004$) and the S-cone isolating stimuli ($p < 0.002$) the increase of contrast threshold was statistically significant when light flash flashes were applied before the sinewave gratings. However, no significant increase was found in the case of the L-M stimuli ($p = 0.113$).

The magnitude of the increments was determined as the ratio of thresholds with and without flashing light stimuli. The mean ratio for achromatic stimuli was 1.928 (median: 1.985; SD: 0.419), for the L-M stimuli it was 1.123 (median: 1.208; SD: 0.233), while for the S-cone