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Blur adaptation: Contrast sensitivity changes and stimulus extent

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ABSTRACT

A prolonged exposure to foveal defocus is well known to affect the visual functions in the fovea. However, the effects of peripheral blur adaptation on foveal vision, or vice versa, are still unclear. In this study, we therefore examined the changes in contrast sensitivity function from baseline, following blur adaptation to small as well as laterally extended stimuli in four subjects. The small field stimulus (7.5° visual field) was a 30 min video of forest scenery projected on a screen and the large field stimulus consisted of 7-tiles of the 7.5° stimulus stacked horizontally. Both stimuli were used for adaptation with optical blur (+2.00 D trial lens) as well as for clear control conditions. After small field blur adaptation foveal contrast sensitivity improved in the mid spatial frequency region. However, these changes neither spread to the periphery nor occurred for the large field blur adaptation. To conclude, visual performance after adaptation is dependent on the lateral extent of the adaptation stimulus.

1. Introduction

It is well known that our visual system continuously changes its response characteristics based on the recent visual experience. For example, we can adapt to a visual environment with high or low contrast and thereby decrease or increase the contrast sensitivity (CS) respectively (Blakemore & Campbell, 1969; Kwon et al., 2009; Webster & Miyahara, 1997). Adapting to blur induced by defocus can also produce changes in visual acuity and contrast sensitivity (Mon-Williams et al., 1998; Ohlendorf & Schaeffel, 2009; Pesudovs & Brennan, 1993; Rajeev & Metha, 2010; Rosenfield, Hong, & George, 2004). It is important to understand the mechanism of this defocus-induced blur adaptation, e.g., in myopia development research and when evaluating spectacles and intraocular lenses that changes the peripheral blur. Most of the previous research on defocus-induced blur adaptation has been restricted to foveal and parafoveal blur stimulus. Extending the blur stimulus also to the periphery during blur adaptation will mimic the natural viewing conditions and give better insights about the underlying mechanism.

1.1. Contrast sensitivity changes following defocus adaptation

Defocus reduces contrast across spatial frequencies, with a small reduction for low spatial frequencies and increased reduction for middle and higher spatial frequencies. Defocus induced blur adaptation is therefore similar to low contrast adaptation. Defocus-induced blur adaptation has been reported to increase suprathreshold contrast sensitivity at 3.22 cycles/degree (cpd) (Ohlendorf & Schaeffel, 2009). Increases in contrast sensitivity were also reported at 8 and 12 cpd when the visual evaluation was performed with defocus (Rajeev & Metha, 2010). However, there is one report that instead found a decrease in contrast sensitivity for a large range of spatial frequencies (from 5 cpd to 25 cpd) following adaptation with a +2.00 D defocus (Mon-Williams et al., 1998).

1.2. Letter acuity changes following defocus adaptation

Adaptational changes in contrast sensitivity will also influence letter acuity although there are other factors like learning, which need to be considered. Most studies on blur adaptation following defocus exposure evaluated letter acuity changes. The reported improvement in high contrast letter acuity following blur adaptation is quite varying, ranging from two letters while adapting to subjects' own myopic refractive error (Pesudovs & Brennan, 1993) to around three lines while adapting to +2.50 D blur (George & Rosenfield, 2004). Rosenfield, Hong, & George, 2004 and George & Rosenfield, 2004 also noted an improvement in low contrast grating resolution in myopic subjects.

1.3. Adaptation stimulus extent in previous studies

In most of the defocus adaptation studies previously mentioned, the adaptation task was movie watching on a computer

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or a television monitor while wearing defocus lenses. This type of adaptation task is commonly employed to ensure attention and fixation at a particular distance. However, it restricts the adaptation stimulus to the fovea and parafovea. So far, there is only one report, in which the visual acuity was evaluated in the fovea and out to 10° nasal visual field (Mankowska et al., 2012). Similar vision improvements were found in fovea and parafovea. It should be noted that the adaptation task was movie watching on a television screen from the distance of 4 m and hence the adaptation stimulus could not have covered the full ±10° field. The authors therefore suggested that the adaptational effects could spread to peripheral locations. If this spread of foveal defocus adaptational effects to peripheral locations does occur, it will be of great importance for myopia development research. Animal studies have shown that peripheral blur can control the growth of the eye and thereby the development of myopia (Charman, 2005; Schaeffel, Glasser, & Howland, 1988; Smith et al., 2005). In addition, it has recently been reported that the correction of central myopia with progressive addition lenses that also induced myopic defocus in the periphery reduces the myopia progression (Berntsen et al., 2013).

To investigate visual field dependence of the blur adaptation effects more thoroughly, we need to meet two pre-requisites: (i) the adaptation stimulus should be extended to the periphery and (ii) a larger range of spatial frequencies and retinal locations in both fovea and periphery should be analyzed. In the current study, we addressed these aspects by comparing contrast sensitivity changes following adaptation with a small and a large field stimulus through measurements of the clear (i.e. not defocused) contrast sensitivity function (CSF) before and after adaptation in the fovea and in the periphery. Measuring CSF is both time consuming and tiring. Fatigue can introduce bias in the results of adaptation studies. To alleviate these problems, we used a quick method to measure CSF, qCSF. This method of assessing the complete shape of the CSF with a Bayesian adaptive estimation strategy was developed and verified by Lesmes et al. (2010) for foveal CSF estimation and was further modified and verified by Rosén et al. for peripheral CSF (Rosén et al., 2014). The qCSF method can estimate the shape of the CSF quickly and thereby allow for multiple measurements before and after adaptation. In addition, separate sessions with contrast sensitivity measurements at separate spatial frequencies and low contrast grating acuity measurements were performed to confirm significant changes noted with the qCSF method.

2. Methods

2.1. Subjects

Four subjects participated in the study: three of the authors who were experienced in the psychophysical procedures and one naïve subject. The authors were not naïve to the purpose of the study, but response bias was controlled by the forced-choice paradigm in the visual evaluation. All subjects had visual acuity or corrected visual acuity of 0.00 logMAR or better. One subject (S2) was myopic (−2.50 D) and was corrected with soft contact lenses. The study protocol followed the tenets of the Declaration of Helsinki and was approved by the regional ethics committee in Stockholm. Informed consent was obtained from all subjects prior to the measurements.

2.2. Experiment procedures

2.2.1. Adaptation conditions and protocol

Two different stimuli (small and large field) were used during adaptation under two optical conditions: (i) with +2.00 D blur induced with trial lens and (ii) clear, i.e. without blur. In total, four adaptation conditions were tested in four separate sessions: Small Field Blur Adaptation (SFBA), Small Field Clear Adaptation (SFCA), Large Field Blur Adaptation (LFBA) and Large Field Clear Adaptation (LFCA). Only the right eye was adapted, while the left was occluded during adaptation. The CSF measurements were made in the right eye fovea (REFovea), the right eye 10° nasal visual field (RE10N), and in the left eye fovea (LEFovea). The measurements in the REFovea was repeated twice and the average of these two measurements was considered for the analysis. The test locations were randomized for both initial and post adaptation measurements. The order of the adaptation conditions was also randomized. To summarize, each session had four initial CSF measurements followed by adaptation and then four CSF measurements after adaptation. A single adaptation session with 30 min of video watching and all visual evaluations lasted about one hour. The sessions were separated at least by two days.

2.2.2. Adaptation

The adaptation stimulus was a high definition video of forest scenery (30 min video clip from an episode of the Planet Earth series by BBC). A high-definition projector with a 1920*1080 pixels resolution was used to project the videos. For small field stimulus, the video was projected with a frame size of 274*154 pixels and for large field stimulus, seven tiles of the small video stacked horizontally were used (Fig. 1). Subjects were seated at a distance of 2 m from the projector screen and the horizontal size of the small and large stimuli were about 7.5° and 42° (26 and 180 cm) respectively. The tiled version was used as the large field stimulus instead of a scaled version in order to have the same frequency content in both adaptation stimuli. For the blur adaptation conditions (SFBA and LFBA), subjects viewed the video through a +2.50 D lens (+0.50 D for 2 m viewing distance and +2.00 D for blur) in front of the right eye. For clear adaptation conditions (SFCA and LFCA), no defocus lenses were used (only a +0.50 D lens for distance compensation) while watching the video. For the viewing distance and the magnification used, the pixel size of the projector was about 1.6 min of arc.

2.2.3. Psychophysical stimulus and apparatus

The stimuli for visual evaluation were presented on a calibrated 19-inch CRT display controlled by a Linux based system with 10-bit gray scale resolution. The mean luminance of the display was 52 cd/m^2. The psychophysical algorithm and monitor calibration were implemented with MATLAB and Psychophysics toolbox routines (Brainard, 1997; Pelli, 1997). An obliquely oriented (45° or 135°) Gabor stimulus with a Gaussian envelope of 0.8° standard deviation was used in a two-alternative forced choice resolution task for all vision testing. The subject's task was to identify the orientation of the grating. The stimulus presentation time was set to 500 milliseconds accompanied by an auditory cue. No feedback was given. An external fixation target (Maltese cross) was used for the RE10N measurements. The monitor and the external fixation target were 4 m away from the subject. Subjects wore a +0.25 D lens during the visual evaluations to compensate for the testing distance. The measurements were conducted in a dark room with natural pupils. The pupil size was monitored with an infrared camera to make sure that it was stable throughout the visual evaluation and not changing between initial and post adaptation measurements. The average pupil size was 6.0 and did not vary by more than 0.5 mm during the initial and post adaptation measurements. A chin-forehead-rest was used to minimize head movements and the pupil camera was also used to monitor the fixation stability.