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Equiblur zones at the fovea and near retinal periphery ☆

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Abstract

Knowledge regarding successive blur discrimination thresholds (i.e., equiblur zones) in depth and across the near retinal periphery, and their relation to blur detection (i.e., depth-of-focus), remains unknown. The blur detection threshold and four successive blur discrimination thresholds were measured psychophysically at the fovea, as well as at retinal eccentricities of 0.25°, 2°, 4°, and 8°. A Badal optometer system was used to assess blur sensitivity monocularly in five visually normal young adults with cycloplegia. The foveal test stimulus consisted of a small irregularly shaped black form, and the peripheral test stimulus consisted of high contrast circular apertures of different radii. Both the group mean blur detection and successive blur discrimination thresholds progressively increased with retinal eccentricity. At retinal eccentricities of 0°, 0.25°, 2°, 4°, and 8°, the group mean blur detection thresholds were 0.53 ± 0.06 D, 0.59 ± 0.10 D, 0.93 ± 0.11 D, 0.98 ± 0.16 D, and 1.25 ± 0.25 D, while the average values of the group mean blur discrimination thresholds across the steps were 0.29 ± 0.01 D, 0.37 ± 0.01 D, 0.48 ± 0.00 D, 0.51 ± 0.01 D, and 0.72 ± 0.02 D, respectively. At each retinal eccentricity, the blur discrimination thresholds were similar to each other, and they were approximately 60% of the blur detection threshold magnitude. These findings provide a conceptual representation of blur perception throughout the central visual field. Possible mechanisms are proposed for the decreased blur sensitivity in the near retinal periphery, as well as for the difference between the blur detection and blur discrimination thresholds.

Keywords: Blur; Depth-of-focus; Retinal eccentricity; Retinal defocus; Visual perception

1. Introduction

Retinal defocus will produce the perception of blur if it exceeds the neurophysiological and neuroperceptual tolerances of the visual system. There are two primary categories of blur perception: blur detection and blur discrimination. Blur detection refers to the allowable range of retinal defocus before the perception of first noticeable blur occurs (i.e., depth-of-focus). In contrast, blur discrimination refers to the allowable range of retinal defocus before an already blurry target appears to be just noticeably blurrier. Thus, blur detection is a threshold metric, and blur discrimination is a suprathreshold metric, with both being related to retinal defocus and the overall perceived retinal-image quality (Ciuffreda et al., 2006).

There have been numerous studies on blur detection and blur discrimination at the fovea, in which blur sensitivity has been investigated as a function of retinal defocus. The results of Jacobs, Smith, and Chan (1989), and more recently Wang and Ciuffreda (2005a), have demonstrated that blur discrimination was more sensitive than blur detection. That is, an individual is more sensitive to a change in target blur than to the initial target blur. This was suggested by the results of a much earlier study (Nachmias & Sansbury, 1974). Moreover, blur discrimination thresholds were found to be independent of baseline defocus level in each study (Jacobs et al., 1989; Wang & Ciuffreda, 2005a). A ratio of less than 1.0 is predicted based on the through-focus changes in modulation

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transfer of the human eye (Charman & Jennings, 1976) and its interaction with the perceptual contrast discrimination ability of the visual system (Wang & Ciuffreda, 2005a). Moreover, neural sharpening (Jacobs et al., 1989) and blur buffering (Wang & Ciuffreda, 2005a, 2005b) have also been proposed as additional mechanisms involved in this phenomenon. Lastly, in two other studies (Campbell & Westheimer, 1958; Walsh & Charman, 1988), sensitivity to oscillatory changes in retinal defocus of a test target was measured as a function of defocus level. The results indicated that an initial increase in blur sensitivity to a focus change occurred as the baseline retinal image was slightly defocused and displaced from the nominal "best focus" point of the eye (i.e., the far point of accommodation). For greater baseline retinal defocus levels, blur sensitivity remained either relatively constant or diminished somewhat depending on properties of the test target (e.g., spatial frequency spectrum) (Walsh & Charman, 1988). The above findings are consistent with current knowledge related to the increased sensitivity found for blur discrimination versus blur detection (Jacobs et al., 1989; Wang & Ciuffreda, 2005a).

However, only few investigations have been conducted on defocus blur detection and discrimination in the retinal periphery (Ronchi & Molesini, 1975; Wang & Ciuffreda, 2004, 2005b). In the Ronchi and Molesini (1975) study, blur detection thresholds (i.e., depth-of-focus) were measured in the far retinal periphery (~7° to 60°). They were found to increase progressively with retinal eccentricity, with far peripheral values as large as 7–12 D. And, in more recent studies (Wang & Ciuffreda, 2004, 2005b), blur detection thresholds were assessed in the near retinal periphery (up to 8°). They too were found to increase progressively with retinal eccentricity. The results from the above investigations demonstrated that blur detection thresholds increased over a wide range of retinal eccentricities as a continuum (Wang & Ciuffreda, 2004). In addition, the initial blur discrimination threshold was also found to increase with retinal eccentricity (Wang & Ciuffreda, 2005b). At each retinal eccentricity, the initial blur discrimination threshold was approximately 60% of the magnitude of the blur detection threshold, as found earlier at the fovea (Wang & Ciuffreda, 2005a). Thus, the initial blur discrimination threshold was more sensitive than blur detection across the near retinal periphery as well as at the fovea.

There has not been any study of blur discrimination as a function of baseline retinal defocus level (i.e., successive blur thresholds) in the near retinal periphery as compared with the fovea. In the present experiment, successive focus-dependent blur discrimination thresholds and their relation to the corresponding blur detection thresholds were assessed psychophysically across the near retinal periphery and at the fovea. This new information provides a conceptual representation of the spatial distribution of the dioptric zones of clarity and blur in depth across the central visual field.

2. Methods

2.1. Subjects

Five visually normal, young adult subjects (22–30 years, mean of 25 years), all of whom were students at the SUNY State College of Optometry, participated in the study. Each had corrected Snellen visual acuity of 20/20 or better in the tested right eye. The group mean spherical and cylindrical refractive correction for the tested right eye was -1.55 ± 1.11 D and -0.33 ± 0.28 D, respectively, which was compensated for by the optical system during all testing. A licensed optometrist performed a vision screening on each subject to avoid any potential adverse side effects from the administration of 1% cyclopentolate HCl, which was used for both cycloplegia and pupillary dilatation during the testing. The study was approved by the Institutional Review Board of the SUNY State College of Optometry, and the experiment was undertaken with the full understanding and written informed consent of each subject.

2.2. Apparatus

The apparatus consisted of a two-channel Badal optical system, which was combined optically with a half-silvered mirror (HSM, transmittance:reflectance = 60:40) (Fig. 1A). This system has been described in detail elsewhere (Wang & Ciuffreda, 2004). One channel (CH1) was positioned in front of and aligned along the line-of-sight of the subject's right eye, and the other channel (CH2) was placed perpendicular to CH1. There was an artificial pupil (AP) of 5 mm diameter positioned in front of the tested eye that was common to both channels. The system's resolution was 0.05 D.

The test target channel (CH1) consisted of a Badal camera lens (L1) of 10 D, an iris diaphragm (ID), a slide holder (SH), and a light box (LB1). The aperture size of the ID was adjustable, which served as the eccentric (0.25°, 2°, 4°, 8°), high-contrast (73%) test target (Fig. 1B). The foveal test target was comprised of an irregularly shaped, annular-like, high-contrast (73%) black form (approximately 7.5 min arc radius), which was mounted on SH behind ID during testing (Fig. 1B). For measurement with the foveal test target, the aperture radius was fixed at 6°. LB1 served as the background illumination for the test target channel. These targets have been used in our earlier investigations (Wang & Ciuffreda, 2004, 2005a, 2005b) and have served as good stimuli for such experiments.

The fixation target channel (CH2) consisted of a Badal ophthalmic lens (L2), a low-contrast (8%) black cross (BC), and a light box (LB2). The BC on transparent film was positioned dioptrically at the far point of the subject's right eye. It served as the fixation target. The line segments of the BC target subtended 10 min arc at the nodal point of the subject's eye and filled the test field. LB2 provided the background illumination for the fixation target channel. The overall background field luminance (LB1+LB2) was 690 cd/m^2.

There was a carefully aligned headrest/chinrest assembly to maintain head stability; with any head movement, a small portion of the test field would disappear due to vignetting, and hence this loss of information functioned as a visual cue for the subject to realign the head. When the head was properly aligned, the entire circular test field was present.

2.3. Procedure

Prior to commencement of testing, all subjects received several minutes of training in the recognition of "just detectable blur" and of "just discriminable blur". With their distance refractive correction in place and gazing monocularly into the distance (6 m) at the center of a series of black aperture-like forms, which served as a representation of the actual eccentric test target arrangement (0.25°–8° in radius) in the apparatus, +0.25 D lenses were added consecutively in the spectacle plane to demonstrate what was meant by small blur changes of the aperture edge. Before commencement of testing, an additional training session for blur detection and blur discrimination at each retinal eccentricity was performed in the test apparatus to minimize any potential learning effects during the experiment.