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Effect of blur adaptation on blur sensitivity in myopes

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Abstract

Although blur adaptation in myopia has been investigated, knowledge regarding its effect on blur sensitivity remains unknown. In the present study, changes in three blur thresholds (i.e., noticeable, bothersome, and non-resolvable blur) were assessed monocularly after 1 h of blur adaptation in myopes. A Badal optical system was used to present either an isolated 20/50 Snellen E or 20/50 lines of text, with the full text field used in the latter condition for all blur judgments. Eight visually normal adult myopes were tested with paralyzed accommodation. All subjects exhibited blur adaptation, with a significant improvement in group mean visual acuity of −0.16 LogMAR. There was a consistent and concurrent significant decrease of 0.15–0.19 D in all blur thresholds for the isolated 20/50 E. However, there was no significant effect of blur adaptation on blur thresholds for the 20/50 text, with large intersubject variability evident. The enhanced blur sensitivity for the isolated E target may in part be attributed to the increased visual resolution following blur adaptation. Differences found in the blur thresholds for the two targets may be related to a variety of neuroperceptual phenomena, in particular lateral masking.

Keywords: Myopia; Blur adaptation; Blur sensitivity; Accommodation; Retinal defocus; Depth-of-focus

1. Introduction

Reduction of visual resolution immediately following defocus blur is a universal optical phenomenon (Smith, 1998). However, some individuals exhibit an apparent compensatory response as a form of perceptual adaptation to longer, sustained periods of blur. For example, previous investigations have demonstrated that when viewing through defocusing lenses over their distance refractive correction, a significant improvement in distance visual acuity (~0.2 LogMAR) occurs in myopes after a sustained period of retinal blur (e.g., 30–180 min) (George & Rosenfield, 2004; Pesudovs & Brennan, 1993; Rosenfield, Hong, & George, 2004), with this phenomenon being referred to as blur adaptation. Blur adaptation has also been observed in emmetropic subjects when defocusing lenses were added (George & Rosenfield, 2004; Mon-Williams, Tresilian, Strang, Kochhar, & Wann, 1998). Presence of blur adaptation was not associated with any change in refractive state at far (Rosenfield et al., 2004).

A possible underlying mechanism to explain the phenomenon of blur adaptation has been proposed invoking an active neurophysiological compensatory process (Georgeson & Sullivan, 1975). That is, the relative gains of visual channels that respond selectively to different spatial frequency bands were assumed to be dynamic and adjustable to provide final-stage perceptual constancy of the retinal-image spatial spectrum (i.e., spatial frequency and contrast aspects) during and/or immediately following optical defocus (Mon-Williams et al., 1998). It has been proposed to occur both in central binocular loci in the visual cortex (Mon-Williams et al., 1998) and in the retina (Diether, Gekeler, & Schaeffel, 2001; Heinrich & Bach, 2001, 2002a, 2002b).

In addition, exposure to either computer-generated blurred images (Webster, Georgeson, & Webster, 2002) or alteration of one's normal pattern of ocular optical aberrations (Artal et al., 2003) have been shown to produce an adaptive effect on retinal-image clarity. It may involve neurological recalibration of perceived contrast to maintain a

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relatively high and fixed correlation related to image interpretation in the visual cortex over a range of visual stimuli. That is, if the visual system adapts either to a new spatial pattern (Webster et al., 2002) or optical aberration pattern (Artal et al., 2003), this neural compensatory process would act to maintain the perceived contrast of patterns over time. Therefore, prior adaptation to either a blurred image or distorted pattern of ocular aberrations may alter the perception of retinal-image clarity, without the necessity of any change in refractive state. Hence, there would be a neural rather than optical shift in the perceived point of optimal retinal-image quality, or "best clear position" (Atchison, Fisher, Pedersen, & Ridall, 2005).

Could there be a link between blur adaptation and accommodative accuracy? In a recent study, an increase in accommodative accuracy at near occurred in myopes during a 3 min period of blur exposure (Vera-Diaz, Gwiazda, Thorn, & Held, 2004). Although this accommodative change was speculated to reflect a sensory adaptation to the prolonged blur exposure, blur sensitivity per se (e.g., depth-of-focus) was not directly assessed. It is known from previous investigations that an increase in visual resolution will reduce the depth-of-focus (Green, Powers, & Banks, 1980) and vice versa (Ciuffreda, Hokoda, Hung, & Semmlow, 1984; Legge, Mullen, Woo, & Campbell, 1987). Thus, the enhanced visual resolution capability after blur adaptation would be predicted to increase blur sensitivity, and thereby decrease the depth-of-focus. In turn, this would lead to increased accommodative accuracy to maintain target clarity, as found in the Vera-Diaz et al. (2004) experiment.

The present study was designed to assess changes in three blur thresholds (i.e., noticeable, bothersome, and non-resolvable blur) (Ciuffreda et al., 2006) in myopes immediately following blur adaptation. In addition, any accompanying improvement in visual acuity and shift in the subjective point of best focus were investigated.

2. Methods

2.1. Subjects

The study was performed on eight myopes, all of whom were either students or faculty at the SUNY/State College of Optometry. Their ages ranged from 23 to 58 years, with a mean of 32 ± 4 years. Spherical refractive errors ranged from −1.0 to −7.5 D, with a group mean of −3.0 ± 0.75 D. Two subjects had −2.25 and −1.25 D of astigmatism, and the remaining six subjects had less than −0.75 D of astigmatism. All described themselves to be either full-time spectacle or contact lens wearers. Distance corrected Snellen visual acuity was at least 20/20 in each eye. None reported or had evidence of ocular, systemic, or neurologic disease or any type of vision dysfunction. Their experience in general psychophysical experiments ranged from modest to high. A licensed optometrist performed a vision screening on each subject to avoid any potential adverse effects from the topical administration of 1% cyclopentolate used for both cycloplegia and pupillary dilation during testing (Jose, Polse, & Holden, 1983).

The experimental procedure was approved by the campus' Institutional Review Board. According to the guidelines of the World Medical Association Declaration of Helsinki (*British Medical Journal* 1991; 302:1194), full understanding and written informed consent were provided by each subject prior to participation in the study.

2.2. Apparatus and test stimuli

A Badal optical system (Fig. 1A) was aligned along the line-of-sight of the subject's right eye. It consisted of a high quality macro camera lens (L) of 10 D, an iris diaphragm (ID), a slide holder (SH), and a small light box (LB). There was an artificial pupil (AP) of 5 mm diameter positioned in the spectacle plane, which served as the effective entrance pupil of the eye for all test conditions. Head stability and eye alignment were maintained with a headrest/chinrest assembly.

Two test targets were used (Fig. 1B). They were comprised of: (1) an isolated 20/50 Snellen letter "E," and (2) three lines of 20/50 letter-size text subtending a visual angle of 7° horizontally and 2° vertically. The test target was placed on the slide holder centered in the visual field. It could be manually displaced very smoothly and slowly by the experimenter (approximately 0.1 D/s) in the Badal apparatus (Mordi & Ciuffreda, 1998; Vasudevan, Ciuffreda, & Wang, in press; Wang & Ciuffreda, 2004, 2005a, 2005b). Resolution was 0.05 D. The above apparatus and test targets have been described in detail elsewhere (Ciuffreda et al., 2006).

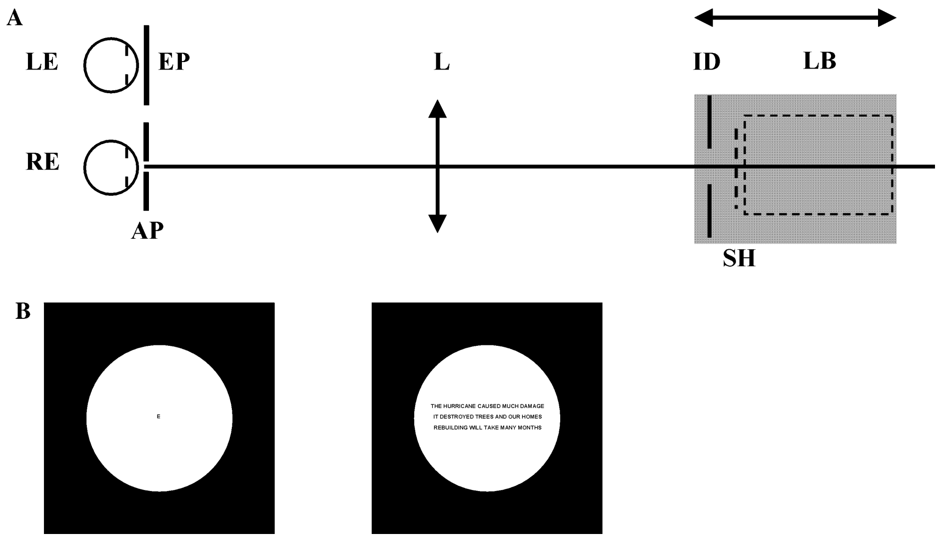

Fig. 1. (A) Top view schematic representation of the Badal test apparatus. Symbols: LE, left eye; RE, right eye; EP, eye patch; AP, 5 mm aperture; L, Badal lens; ID, iris diaphragm; SH, slide holder; and LB, light box. Arrow above LB indicates direction of target movement. (B) Two test targets: 20/50 E and 20/50 text.

2.3. Procedures

2.3.1. Training and preparation

Pre-experimental training was performed on all subjects. This familiarized them with the recognition of "noticeable blur," "bothersome blur," and "non-resolvable blur" in the test apparatus by manipulation of the test target position in the Badal system (Ciuffreda et al., 2006). The refractive correction of the tested right eye was fully compensated by the optical system. One practice session was conducted in each subject. It consisted of three parts for each target. Each part took 5 min to familiarize the subject with each of the blur criteria. The instructions, blur criteria, and the practice effects were consistent across all subjects. The total training time was 30 min, which was similar to the period of the test session for each subject. "Noticeable blur" referred to the minimum amount of defocus blur introduced for which the target became just slightly less sharp than its maximally sharp appearance at the subjective point of best focus. "Bothersome blur" referred to the minimum amount of defocus blur introduced for which the target was perceived to be annoying and would presumably impair task performance, such as reading or identifying objects; however, the letter or text still remained recognizable. "Non-resolvable blur" referred to the minimum amount of defocus blur for which the letter or the text became incapable of being recognized and read, but was still visible. For the 20/50 text target, the subject was instructed to attend to the full text and use the full test field for all blur judgments, while fixating upon the letter "E" of one of the centrally positioned words (i.e., "trees") in the visual field. Thus, the central fixational target for both the 20/50 text and the 20/50 isolated E were identical.

Following the practice trials, all subjects were cyclopleged with two drops of 1% cyclopentolate instilled 5 min apart (Rosenfield & Abraham-Cohen, 1999; Wang & Ciuffreda, 2004). Maximum pharmacological effect took approximately 30 min to attain (Rosenfield & Linfield, 1986). During this 30 min period, subjects were instructed to maintain their distance fixation binocularly with their habitual distance spectacle correction in place. They watched a DVD movie on a computer screen (4.3° horizontally and 3.5° vertically) with full room illumination at a viewing distance of 5 m in the laboratory environment. Average screen luminance was 25 cd/m^2 (Minolta Camera Co., Ltd, Minolta Luminance Meter LS-100). This provided the subjects with a continuous period of clear vision prior to commencement of the experiment.

2.3.2. Pre-adaptation measurements

The refractive state of the subject was tested objectively with a high resolution (0.12 D) infrared autorefractor (Canon R-1, Lake Success, NY) to ensure presence of the full cycloplegic effect. The subject was instructed to gaze into the distance (5 m, 0.2 D), and then attempted to focus on a near target (33 cm, 3 D). Autorefractor readings at the far and near distances were compared. If the accommodative states differed by 0.25 D or less, which suggested presence of full cycloplegia, then the experiment commenced. The experiment was completed before dissipation of the cycloplegic's maximum effect (Mordi, Tucker, & Charman, 1986; Rosenfield & Linfield, 1986).

Once cycloplegia and pupillary dilation were achieved, high contrast (>90%) visual acuity of the right eye was assessed through a +2.50 D blurring lens and a 5 mm artificial pupil placed over the habitual distance spectacle correction. The left eye was fully occluded with a black eye patch. An ETDRS 2000 series vision chart (Precision Vision™, La Salle, IL) was placed at a viewing distance of 4 m (Ferris, Kassoff, Bresnick, & Bailey, 1982). Subjects were instructed to read the vision chart letter by letter, starting with the top row. The difference between adjacent lines was 0.1 LogMAR units. There were five letters on each line, and the LogMAR score assigned for each correctly read letter was 0.02 units. A lower score represented better visual acuity. The subject was encouraged to guess when he or she had difficulty reading a letter. Visual acuity was specified as the smallest line for which three or more letters were correctly identified.

After measurement of visual acuity, the subject was instructed to look into the Badal optical system with the right eye through the 5 mm artificial pupil; the left eye (LE) was fully occluded with a black eye patch (EP). The subjective point of best focus was determined under each of the four test conditions: pre-adaptation with the isolated E, pre-adaptation with the text, post-adaptation with the isolated E, and post-adaptation with the text. The subject displaced the test target mounted on the slide holder fore and aft in the Badal optometer, until it appeared to be maximally "clear" (Atchison et al., 2005). This procedure was repeated three times, and the average position was recorded as the "subjective point of best focus" (i.e., the "best clear position") per the criterion of Atchison et al. (2005). This served as the reference point for the subsequent blur threshold measurements.

An ascending method of limits was used for the blur sensitivity assessment. First, the target was positioned at the subjective point of best focus. Then, it was carefully and slowly displaced by the experimenter away from this point at a rate of approximately 0.1 D/s (Mordi & Ciuffreda, 1998; Vasudevan et al., in press; Wang & Ciuffreda, 2004, 2005a, 2005b). The subject was instructed to depress a small handheld clicker when the first, slight detectable blur of the test target was perceived, which was the "noticeable blur" threshold. Then, the test target was slowly and carefully displaced further away from this position. The subject was instructed to indicate when blur of the target became just bothersome or annoying to look at, and furthermore, would presumably adversely affect task performance. This represented the "bothersome blur" threshold. Lastly, the test target was further displaced slowly and carefully away from this position, until the subject indicated that the test target was just not recognizable or readable. This point was the "non-resolvable blur" threshold. This procedure was repeated three times for each of the two test targets. The mean values for each blur threshold were averaged within and across subjects, and then converted to diopters. Due to physical limitations of the device, the three blur thresholds were only assessed distally relative to the subjective point of best focus (Ciuffreda et al., 2006). Order of presentation of the two target types was counterbalanced across subjects.

2.3.3. Blur adaptation

Blur adaptation was induced by placing +2.50 D spherical spectacle lenses binocularly over the distance correction of the subject for a continuous 1 h period. To achieve the maximum blur effect, subjects maintained their fixation on the computer screen to view the movie at a distance of 5 m in the dark room throughout the trial period. Average computer screen luminance was 22 cd/m^2 (Minolta Camera Co., Ltd, Minolta Luminance Meter LS-100).

2.3.4. Post-adaptation measurements

Immediately after the period of blur adaptation, the assessments of visual acuity and of blur sensitivity were repeated in each subject. This was followed by objective measurement of refractive state with the Canon R-1 autorefractor.

2.4. Control experiment

A control experiment was performed on three of the subjects. The entire aforementioned procedure was repeated, except that 1 h of in-focus vision replaced the 1 h of blurred vision at far.

3. Results

The group mean visual acuity measured through the +2.50 D blurring lens was 0.73 LogMAR (SEM = ±0.07) before blur adaptation and 0.58 LogMAR (SEM = ±0.08) after blur adaptation. Individual changes in LogMAR visual acuity ranged from −0.06 to −0.26, with a significant group mean improvement of −0.155 (SEM = ±0.02) [$t(7) = -6.35$, $p < 0.001$], which was similar to the results of previous studies (George & Rosenfield, 2004; Rosenfield et al., 2004). This enhancement of visual resolution occurred without significant change in refractive state. The group mean change in spherical equivalent refraction was

0.10 ± 0.15 D [$t(7) = 1.82$, $p = 0.11$], which was less than the resolution of the Canon R-1 autorefractor (i.e., 0.12 D).

The group mean blur thresholds are presented in Fig. 2 and Table 1. For both test targets, they progressively and significantly increased with each successive criterion (i.e., noticeable blur < bothersome blur < non-resolvable). For each blur criterion, the post-adaptation blur threshold was less than its pre-adaptation counterpart. Thus, on average, blur sensitivity increased after a sustained period of retinal-image blur. A two-way ANOVA revealed significant effects of both blur adaptation [$F(1,42) = 8.13$, $p < 0.01$] and blur criterion [$F(2,42) = 44.52$, $p < 0.001$] on blur sensitivity for the isolated 20/50 E. For the 20/50 text, there was a significant effect of blur criterion [$F(2,42) = 26.64$, $p < 0.001$]; however, the effect of blur adaptation on blur sensitivity was not significant [$F(1,42) = 0.79$, $p = 0.38$].

The group mean and individual results of the dioptric blur threshold changes after blur adaptation relative to the zero baseline are presented in Fig. 3. First, for the isolated 20/50 E, significant changes were found. The group mean threshold change was −0.15 ± 0.05 D for noticeable blur [$t(7) = -2.91$, $p < 0.05$], −0.19 ± 0.03 D for bothersome blur [$t(7) = -5.92$, $p < 0.001$], and −0.19 ± 0.07 D for non-resolvable blur [$t(7) = -2.88$, $p < 0.05$]. A one-way ANOVA revealed no significant effect of blur criteria on the mean threshold changes [$F(2,21) = 0.16$, $p = 0.85$]. The individual results were consistent with the group findings. All subjects (except one for the non-resolvable blur threshold) exhibited a post-adaptation threshold decrease across the three blur criteria. Second, for the 20/50 text, the group mean threshold change relative to the zero baseline was −0.08 ± 0.11 D for noticeable blur [$t(7) = -0.70$, $p = 0.50$], −0.11 ± 0.12 D for bothersome blur [$t(7) = -0.86$, $p = 0.42$], and −0.09 ± 0.15 D for non-resolvable blur [$t(7) = -0.62$, $p = 0.55$]. A one-way ANOVA revealed no significant effect of blur criteria on the mean threshold changes [$F(2,21) = 0.01$, $p = 0.98$]. In contrast to the results for the isolated 20/50 E, there was large intersubject variability in the individual results with the text target. For each blur criterion, approximately half of the subjects exhibited a decreased blur threshold, while the other half manifested an increased blur threshold. Thus, while the group mean threshold value changes were all directionally appropriate, the large intersubject variability nullified any possible effect. Lastly, there was no significant correlation between the visual acuity improvement and blur threshold change under all test conditions for each target (r value range: −0.21 to +0.48, $p > 0.05$).

With respect to the post-adaptation change in the subjective point of best focus, there was a significant hyperopic shift of 0.28 ± 0.09 D [$t(7) = 2.96$, $p < 0.05$], with a range from −0.05 to 0.65 D, for the isolated 20/50

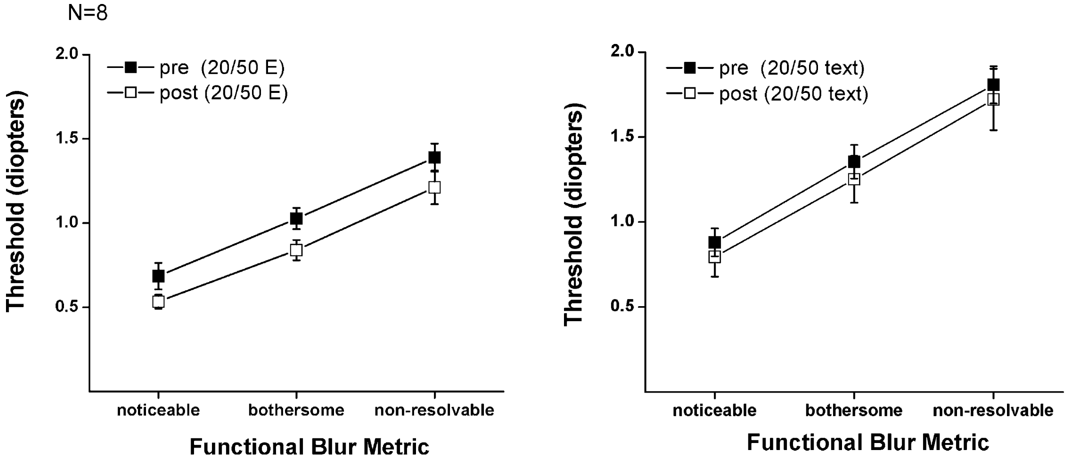

Fig. 2. Pre- and post-adaptation blur thresholds as a function of blur criterion for the two test targets. Plotted is the mean ±1 SEM.

Table 1
Comparison of results with Ciuffreda et al. (2006)

Target	Parameter (diopters)	Study			
		Ciuffreda et al. (2006) ($n = 13$)[a]	Present study ($n = 8$)		
			Pre-adaptation	Post-adaptation	Post–pre
20/50 E	Noticeable	0.63 ± 0.06	0.69 ± 0.08	0.53 ± 0.04	−0.15 ± 0.05
	Bothersome	1.02 ± 0.10	1.03 ± 0.06	0.84 ± 0.06	−0.19 ± 0.03
	Non-resolvable	1.43 ± 0.14	1.39 ± 0.08	1.21 ± 0.10	−0.19 ± 0.07
20/50 Text	Noticeable	0.83 ± 0.09	0.88 ± 0.08	0.80 ± 0.12	−0.08 ± 0.11
	Bothersome	1.34 ± 0.12	1.35 ± 0.10	1.25 ± 0.14	−0.11 ± 0.13
	Non-resolvable	1.89 ± 0.15	1.81 ± 0.11	1.72 ± 0.18	−0.09 ± 0.15

[a] This population consisted of young adult subjects ages 21–36 years. The group mean spherical and cylindrical refractive corrections of the tested eyes were −0.65 ± 0.50 D and −0.59 ± 0.18 D. Spherical equivalent refractive corrections ranged from −4.44 to +2.63 D.

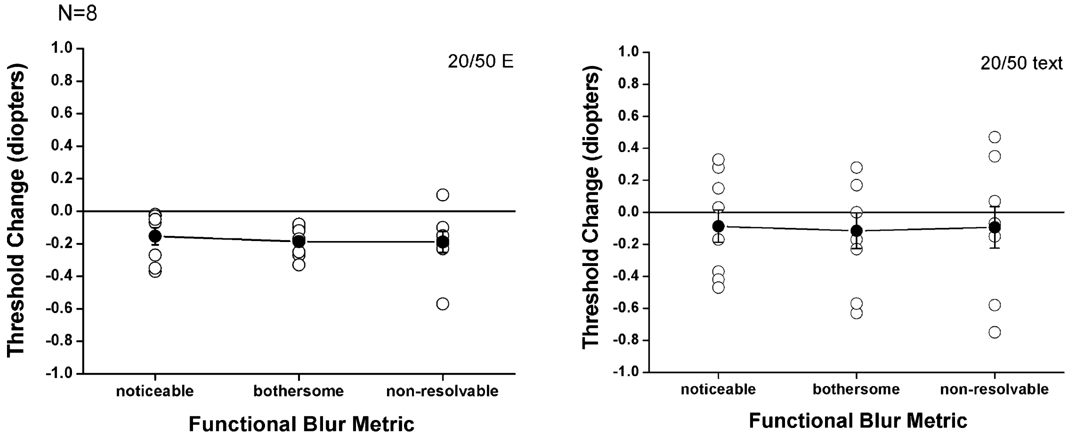

Fig. 3. Blur threshold changes as a function of blur criterion for the two test targets. Plotted is the mean ±1 SEM. Symbols: (●) group mean results and (○) individual mean results.

E. However, there was no significant shift for the 20/50 text (0.26 ± 0.20 D) [$t(7) = 1.30$, $p = 0.23$], with a range from −0.63 to 0.9 D.

The results of the control experiment are presented in Table 2. Changes in blur thresholds were considerably smaller than those found for the blur adaptation paradigm for the isolated 20/50 E. While this change was not evident for the 20/50 text, considerably larger variability was found (Fig. 4).

Table 2
Results of the control experiment ($n = 3$)

Change in measurements	Test condition	
	Adaptation	Control
Visual acuity (LogMAR)	−0.21 ± 0.03	0.03 ± 0.01
Blur thresholds (diopters)		
Isolated 20/50 E		
Noticeable	−0.16 ± 0.10	0.02 ± 0.04
Bothersome	−0.20 ± 0.03	−0.05 ± 0.05
Non-resolvable	−0.19 ± 0.02	0.01 ± 0.04
20/50 Text		
Noticeable	0.04 ± 0.21	−0.05 ± 0.01
Bothersome	−0.06 ± 0.29	−0.03 ± 0.06
Non-resolvable	−0.07 ± 0.36	−0.08 ± 0.09

4. Discussion

4.1. Comparison with our previous experimental work

A comparison was made with previous work using identical equipment and similar procedures (Ciuffreda et al., 2006). As shown in Table 1, the current data for the pre-adaptation blur thresholds were similar to the previous findings, with an average absolute difference across all the test conditions of 0.04 ± 0.01 D, which was less than the resolution limit of the Badal device (0.05 D).

4.2. Possible mechanisms involved in blur adaptation and accompanying changes in blur sensitivity

The present experiment demonstrated that visual resolution measured through defocusing lenses improved in myopes following a 1 h exposure to optical defocus blur at far. This confirmed the findings of previous studies

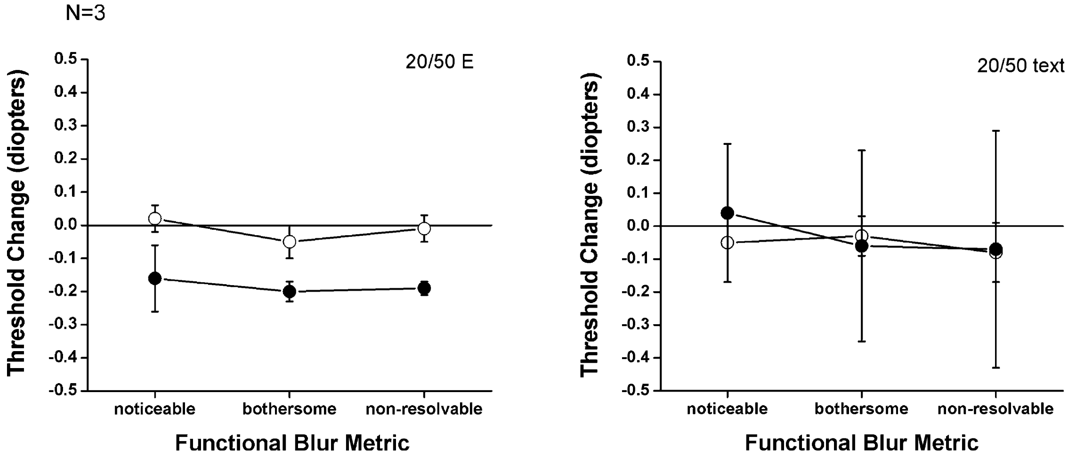

Fig. 4. Blur threshold changes as a function of blur criterion in the experimental (with blur adaptation) and the control (without blur adaptation) conditions for three subjects. Symbols: (●) results with blur adaptation and (○) results without blur adaptation.

(George & Rosenfield, 2004; Mon-Williams et al., 1998; Pesudovs & Brennan, 1993; Rosenfield et al., 2004). More importantly, the results of the present study suggested that the enhancement of blur sensitivity (e.g., the decrease in depth-of-focus) may in part be attributed to the increase in visual resolution (Green et al., 1980) present after blur adaptation. This postulation was also supported elsewhere. A recent investigation by Subramanian and Mutti (2005) found that contrast sensitivity at a high spatial frequency (15.13 c/deg) increased after blur adaptation. This is consistent with improvement in visual resolution after the blur exposure in the present study. Furthermore, they speculated that the accommodative lag would concurrently decrease, which is consistent with our depth-of-focus findings.

The improvement in visual resolution following blur adaptation may reflect a neural compensatory process in response to sustained optical defocus, as has been speculated by others (Dealy & Tolhurst, 1974; Georgeson & Sullivan, 1975; Greenlee & Magnussen, 1988; Mon-Williams et al., 1998). For example, Mon-Williams et al. (1998) found a decrease in contrast sensitivity in the mid-range spatial frequencies after exposure to optical defocus, with the low and high frequencies remaining unchanged. They postulated that this was achieved by relative gain adjustment of visual channels that responded selectively to the different spatial frequency bands. The reduced sensitivity to mid-range spatial frequency band would lead to an unmasking of the low contrast luminance profile change in the high spatial frequency band with optical defocus, which in turn would increase the resolution ability of the high spatial frequency components in a defocused and blurry image (Mon-Williams et al., 1998). The gain adjustments were assumed to occur continuously by modulation of inhibitory interactions between the different visual channels (Dealy & Tolhurst, 1974; Georgeson & Sullivan, 1975; Greenlee & Magnussen, 1988). Through this compensatory process, the visual system could maintain relative constancy of its adapted pattern (i.e., contrast amplitude spectrum) (Mon-Williams et al., 1998). Thus, one might invoke a perceptual contrast constancy mechanism (Georgeson & Sullivan, 1975), as is true for other types of perceptual constancies (e.g., size and shape) (Epstein, 1977).

The group mean change in blur sensitivity after blur adaptation for the extended target (i.e., 20/50 text) was not significant and was smaller than that found for the isolated 20/50 E. In addition, considerable intersubject variability was found. The following four mechanisms may explain the difference in results between the two test targets. First, in an earlier experiment, it was shown that blur sensitivity (i.e., blur detection thresholds) decreased with retinal eccentricity in the near retinal periphery (0–8° radius) (Wang & Ciuffreda, 2004). As a result, more retinal defocus would be required to generate the sensation of blur in one's peripheral vision as compared with the fovea. This notion was also supported by the perceptual phenomenon of "sharpness overconstancy" (Galvin, O'Shea, Squire, & Govan, 1997). They demonstrated that an edge, which was blurry when an observer looked at it foveally, appeared to be sharp with eccentric gaze. Therefore, greater defocus of the retinal-image would be required in the periphery versus the fovea to produce the perception of blur and related blur adaptation. Second, the magnitude of blur adaptation would be predicted to decrease as a function of retinal eccentricity for the above reasons. Hence, as compared with the isolated 20/50 E, the peripheral retina's contribution to overall blur adaptation was larger for the 20/50 text target. Therefore, the post-adaptation signals pooled both across the near retinal periphery and the fovea would be averaged and weighted, which would effectively reduce the aggregate blur adaptation effect. Hence, the decreased amplitude of this adaptive effect would result in a smaller change in blur sensitivity for the extended text target. Third, variation in the gradient of eccentricity-dependent visual attentional (Giorgi, Soong, Woods, & Peli, 2004; Shani & Sagi, 2005) and optical (e.g., ocular aberrations) (Guirao & Artal, 1999) distributions may have contributed to the individual variability in changes of blur sensitivity following the adaptation, as size of the test target increased. And, fourth, the phenomenon of lateral masking may also contribute to the markedly reduced and more variable post-adaptation blur sensitivity changes found for the 20/50 text target. Lateral masking affects the detectability, discriminability, and/or recognition of a target (Chung, Levi, & Legge, 2001). It has been found that the presence of surround elements produced threshold elevation for the detection of changes in contrast, spatial frequency, and orientation (Wilkinson, Wilson, & Ellemberg, 1997). Furthermore, they found that lateral masking increased in strength with retinal eccentricity in the near retinal periphery (Wilkinson et al., 1997). Therefore, contrast and spatial frequency discrimination abilities would be predicted to be relatively reduced in the periphery of the text as compared with the foveally viewed isolated letter E. Thus, when the contrast and spatial frequency components were gradually and concurrently degraded with progressive optical defocus in the Badal system, the ability to discriminate these two features of the 20/50 text target would be predicted to be worse than for the isolated 20/50 E, as found in the present study.

4.3. Possible mechanisms involved in changes of the subjective point of best focus after blur adaptation

A significant relative hyperopic shift in the subjective point of best focus was found for the isolated 20/50 E following blur adaptation. This suggested a neural recalibration process. That is, the visual system established a new reference point in visual space for perceptual "clarity" of the retinal-image due to the immediately prior blur experience. The retinal-image corresponding to a particular point in the relative hyperopic refractive state was now considered by the brain to be "clear" and "in focus" after a sustained period of retinal defocus, despite the refractive state remaining unchanged. Since accommodation was paralyzed during all testing in the current study, no actual lens-based shift in "best focus" could actually occur. However, a sustained period of myopic defocus with plus fogging lenses would be sufficient to adapt one's visual system to the blurriness at far. Thus, the eye would "neuroperceptually" shift to a relatively more hyperopic status for the distance target. As a result, the distance visual scene would appear to be less blurry. Furthermore, this relative hyperopic shift biased the subjective far point closer towards infinity, which was consistent with the present findings of a concurrent decrease in the depth-of-focus (see Ciuffreda, 1998 for review). This hyperopic directional shift would act to reduce the blur effect of the plus lenses, and therefore it would be a desirable adaptive compensatory phenomenon.

4.4. Possible underlying mechanisms to explain the previous findings of more accurate accommodation following blur adaptation in myopes

The present findings bear relation to a recent study of accommodation in myopes (Vera-Diaz et al., 2004). An increased accommodative response (i.e., improved accommodative accuracy) was found in young adult myopes during 3 min blur exposure with a diffusing filter (Vera-Diaz et al., 2004). This diffusing filter reduced the subject's visual acuity to 0.7 LogMAR, which was similar to that found in the present study with the +2.50 D blurring lenses. Their result suggested that adaptation to blur increased the gain of accommodation system, which was believed to reflect a sensory adaptive phenomenon (Vera-Diaz et al., 2004). The findings of the present study provide evidence for this postulation. Enhanced blur sensitivity (i.e., smaller blur thresholds) following blur adaptation would decrease the depth-of-focus, and thus result in an increase of accommodative accuracy at near to maintain image clarity. This proposed mechanism was also supported by previous knowledge of the relationship between visual resolution and depth-of-focus (Green et al., 1980; see Wang & Ciuffreda, 2006 for a review), in which depth-of-focus is predicted to become smaller with the improvement of visual acuity. In summary, blur adaptation led to improving vision resolution, which would reduce the depth-of-focus, and therefore increase accommodative accuracy.

4.5. Basic and clinical implications

Knowledge of the effect of blur adaptation on blur sensitivity changes in myopes may have important basic implications in models of accommodative control. A modification to the Hung and Semmlow (1980) static model of accommodation was suggested by Jiang (2000), in which an "accommodative sensory gain" (ASG) element was added immediately in front of the conventional DSP element (i.e., "deadspace operator" or depth-of-focus). It was assumed that this ASG component reflected the "stimulus effectiveness" to drive the accommodative system. Thus, the ASG would act to modulate the effective depth-of-focus: a degraded stimulus would decrease the ASG, and hence increase the depth-of-focus, and vice versa. However, if this degraded stimulus persisted for a period of time, one might predict that blur adaptation would enhance the ASG to increase the stimulus effectiveness, thus attempting to maintain constancy of contrast perception.

In the current study, only myopic individuals were tested. This was done for two reasons. First, myopes were subjects of convenience to demonstrate adaptive responses to blur exposure, as myopes have shown reasonably consistent blur adaptation, with it being slightly larger than that found in emmetropes (George & Rosenfield, 2004). Second, anecdotally myopes have reported clearer vision upon awakening from sleep without their corrective lenses than under the same conditions later in the day (Pesudovs & Brennan, 1993). Further investigations on changes in blur sensitivity and accompanying accommodative responses over short-term/long-term blur exposure period in different refractive groups are warranted. This may provide new insights related to variations in accommodative accuracy in myopes as well as myopic progression (Hung & Ciuffreda, 1999a, 1999b; Rosenfield et al., 2004; Vera-Diaz et al., 2004).

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