Increased accommodation following adaptation to image blur in myopes

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Prolonged exposure to blurred images produces perceptual adaptation (M. A. Webster, M. A., Georgeson, & S. M. Webster, 2002). The purpose of this study is to test whether in addition to the reported change in perceived blur there is also a change in accommodation. Young adult (aged 18 to 31 years) myopic (*n* = 23) and emmetropic (*n* = 17) subjects participated in the study. Myopes were tested with contact lenses and had corrected monocular visual acuity of 20/20 or better. Accommodation was measured binocularly with a PowerRefractor, an eccentric infrared photorefractor. Accommodation for a near target (high-contrast text at 0.33 m) was measured for 2 min before and immediately after 3 min of blur exposure. Blur was induced using 0.2 Bangerter diffusing filters in front of both eyes. In addition, accommodation was measured for a far target (high-contrast letters at 4.0 m) before and after the near measurements, with each subject's initial far readings used as a baseline for calculating the accommodative responses at near. Compared to the pre-adaptation level, myopes showed a significant (*p* < .01) increase in the near accommodative response after 3 min of blur adaptation, while accommodation to the near target in emmetropes did not change. In a second experiment using monocular viewing, the increase of accommodation found in myopes was shown to occur during the period of blur exposure. The refractive group differences in the accommodative response may be related to differences in the habitual response to image clarity between myopes and emmetropes under normal viewing conditions.

Keywords: blur, adaptation, accommodation, myopia, emmetropia, oculomotor, neurosensory

Introduction

Recent models of human myopia propose retinal defocus as a causative factor in refractive error development (Flitcroft, 1998; Jiang & Morse, 1999; Hung & Ciuffreda, 1999, 2000). In these models, the growing eye works as a feedback system designed to maintain the clarity of the retinal image by modulating eye growth according to the magnitude of retinal defocus. Retinal defocus would, therefore, serve as a stimulus regulating the rate of axial elongation in myopia.

During normal visual development the eye achieves a close match between the power of its optics and its axial length with the result that far images are focused on the retina without accommodative effort (emmetropia). This emmetropization process is partly an optical consequence of proportional eye growth, and thus passive in nature. However, experimental models of myopia also provide strong evidence for an active role of defocus in the emmetropization process (Wallman & Adams, 1987; for a review, see Wildsoet, 1997). Degrading a retinal image by frosted eye occluders produces elongated eyes and "form-deprivation myopia" in a variety of animal species, providing evidence for a feedback system that correlates eye growth and the magnitude of retinal defocus. Partial frosting degrades the retinal image in a more subtle manner, leading to the development of lesser amounts of myopia (Bartmann & Schaefffel, 1994; Smith & Hung, 1999). In addition, a number of studies have demonstrated that experimental myopia may be induced by placing negative lenses before the eyes in various animal species (e.g., chick, guinea pig, tree shrew, and marmosets) (for reviews, see Edwards, 1996, and Norton, 1999). Although the exact mechanism controlling emmetropization remains uncertain, a number of studies (Graham & Judge, 1999; Schaeffel & Diether, 1999; Smith & Hung, 1999) highlight the fundamental role played by blur in the regulation of eye growth.

Disruption of the emmetropization process results in the development of refractive errors, of which myopia is the most common. Myopia is a highly significant problem, not only because of its increasing prevalence-more than 80% in

some Asian countries (Lin et al., 2001), but also because it is a high risk factor for vision-threatening conditions (e.g., retinal detachment and glaucoma). These conditions are due to the stresses produced in the posterior segment of the eye as a result of the excessive increase in axial length.

According to clinical observations, the visual performance (e.g., visual acuity [VA] and contrast sensitivity function [CSF]) of corrected myopic subjects improves after a period of uncorrected vision compared to the performance when the correction is worn at all times (Pesudovs & Brennan, 1993). This phenomenon can be interpreted as an increased tolerance to blur (learning process), or an improvement in vision due to neural or optical adjustments within the visual system (Mon-Williams, Tresilian, Strang, Kochhar, & Wann, 1998).

Myopes normally have reduced sensitivity to blur in comparison to emmetropes. Rosenfield and Abraham-Cohen (1999) showed that on average, myopes have increased blur thresholds. Various models of human myopia (Jiang, 1997; Flitcroft, 1998; Hung & Ciuffreda, 1999) suggest that higher blur thresholds may be related to increased accommodative errors and the development of myopia. The increased accommodative lag found in some myopic subjects (Gwiazda, Thorn, Bauer, & Held, 1993; Jiang, 1997; Abbott, Schmid, & Strang, 1998) would produce a hyperopic retinal defocus that may play a significant role in myopia development and/or progression.

More recently, prolonged exposure to blurred images has been shown to produce perceptual adaptation. Webster, Georgeson, and Webster (2002) found that exposure to a blurred image caused the original image, which had previously been interpreted as clear, to appear to be too sharp. These aftereffects appeared after brief periods (a few seconds) of adaptation. Although the authors did not identify the refractive errors of the subjects, they did note that "these adaptation effects are thus important for understanding. . . how vision changes during development and with refractive errors." Judgments of focus are strongly biased by adaptation to blurred or sharpened versions of an image. Adaptive tuning may be important in calibrating and maintaining the correlation between the image processing in the visual cortex and natural visual stimuli during visual development. Variations of the environment and/or the observer, such as in refractive errors, may alter this correlation. The adjustments taking place by adaptation to blur may be important in maintaining a constant perception of the world. Furthermore, these adaptation effects can potentially alter the accommodative response to the image, by altering sensitivity or responsiveness of the accommodative system to blur.

The present study was designed to test whether the reported adaptation in perceived blur produced by exposure to blurred images is accompanied by a change in accommodation, and whether that change differs between emmetropes and myopes.

Methods

Subjects

Forty young adult (mean age = 24.88 ± 3.23 years) myopic (mean refraction = –3.46 ± 1.86 D; n = 23) and emmetropic (mean refraction = +0.03 ± 0.15 D; n = 17) subjects participated in the study. Myopes were tested with soft contact lenses and all subjects had corrected monocular visual acuities of 20/20 or better. Subjects with astigmatism > 1.00 D were not included in the study. The research followed the tenets of the Declaration of Helsinki, and informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study.

Apparatus: the Power Refractor

The accommodative response was measured binocularly with the PowerRefractor (PlusOptixs, Germany), an eccentric infrared photorefractor that converts the slopes of the brightness distributions in the pupil into refractive error. Figure 1 shows the appearance of the screen of the PowerRefractor during the dynamic measurement of accommodation. The PowerRefractor can record the pupil sizes, the refraction in the vertical meridian of both eyes, and the angle of convergence of the pupils' axes of both eyes. In its binocular mode, the PowerRefractor measures the slope of the pupil distributions in the vertical meridian every 0.04 s. Detailed descriptions of the PowerRefractor can be found in Choi et al. (2000) and Seidemann and Schaeffel (2002).

Figure 1. Appearance of the screen of the PowerRefractor during dynamic measurement of accommodation. The PowerRefractor can record pupil sizes, the refraction in the vertical meridian of both eyes, and the angle of convergence of the pupils' axes of both eyes.

The PowerRefractor uses a built-in calibration function to determine refractive state from the change of the pixel intensities across the vertical meridian of the pupil (Seidemann & Schaeffel, 2002; Seidemann and Schaeffel 2003). To insure accurate readings, particularly for larger refractive errors, re-calibration of the data was performed in the present study using the method described by Harb, Troilo, and Thorn (2003).

Procedures

Diffusing lenses (0.2 Bangerter Occlusion Foils; The Fresnel Prism and Lens Co., LLC) that induce scatter blur were used to produce an adaptation to blur similar in magnitude to that induced by Webster et al. (2002). The Bangerter Foil induced a reduction of contrast of ~75% on the target used in the experiment. It is primarily a low-pass filter with the transmission characteristics shown in Figure 2. Previous reports have shown that the peak of accommodative responses is found in the region of 5 c/deg, with open-loop conditions being initiated in the region of 0.5 c/deg (Ward, 1987; Matthews & Kruger, 1994; Niwa & Tokoro, 1998).
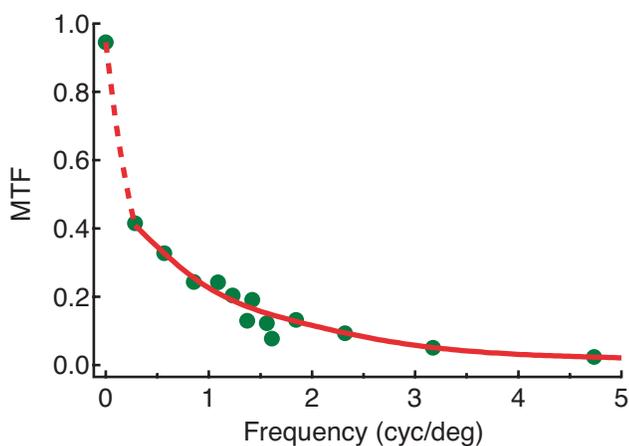

Figure 2. Modulation transfer function (MTF) reduction by the diffusing lenses for various sine wave frequencies. Calculation of the characteristics of the diffusing lenses was done by photographing sine waves simulating the experimental conditions. The digital pictures were Fourier transformed to get amplitude spectra. The amplitude of the blurred sine wave spectrum was divided by the amplitude of the nonblurred sine wave spectrum for the given sine wave frequencies. Due to the abrupt change in the lower frequency region of the MTF, the curve was fitted with two second-order polynomials splined together at 0.28 c/deg. The fitting curves are presented for a visual guide to show the overall shape of the MTF.

Initially, accommodation was measured binocularly for a far (4 m) target (high-contrast 90% letters; logMAR 0.3) for 1 min. Accommodation was then measured while the subjects read a paragraph of high-contrast text (85%) with letter size 10 point at 0.33 m (logMAR 0.5) for 2 min. After this period, blur was induced by the scattering filters during a 3-min period. This time period was chosen as consistent with the adaptation to blur that has been found following this length of blur exposure (Webster et al., 2002). Subjects continued looking at the same text target at 0.33 m during this period of blur adaptation. The text blurred with scattering filters provided a degraded accommodative stimulus during the adaptation period (see movie simulation). Subjects reported that they could not discriminate the letters of the text during this period.

Immediately after the blur exposure period, accommodation at near was measured for a further 2-min period. Lastly, accommodation was measured while subjects viewed the far target (4 m) for 1 min.

Data analysis

Individual raw data were calibrated as described earlier and divided into 10-s intervals. Analyses of mean data for Figure 5 were carried out averaging all post-adaptation data. For purposes of comparison and statistical analysis, each subject's far readings were used as a baseline for calculating the accommodative responses at near.

Control experiments

Data taken during the blur exposure condition were not valid because the diffusing filter was placed between the PowerRefractor and the eye. To understand what was happening to the accommodative response during the period of blur exposure, two additional experiments were carried out.

Measurement of accommodation responses during the blur condition (infrared filter)

The aim of this experiment was to assess accommodative responses during the blur exposure condition. It was performed in a subgroup of subjects (5 myopes and 5 emmetropes). The procedures were the same as described above except that the right eye (measured eye) was covered with an infrared (IR)-only transmitting filter (peak at 720 nm), while the left eye was the fixating eye throughout the experiment. Note that this experiment differs from the main experiment in that it occurs under monocular viewing. Analysis of the data was carried out as formerly described.

Adaptation to open-loop accommodation (dark-focus)

The aim of this experiment was to compare accommodative adaptation following a period of darkness to accommodative adaptation following blur exposure described in the main experiment. It was performed in a subgroup of subjects (4 myopes and 2 emmetropes). The procedures were the same as described above except that the 3 min of blur were replaced with a 3-min open-loop accommodation condition, with the subjects in complete darkness. Analysis of the data was carried out as described above.

Results

[Figure 3a](#) presents the accommodative responses of all emmetropes during 10-s intervals. These data revealed stable responses over time for each of the conditions tested. For distance viewing (4 m), accurate accommodative responses were found for all emmetropic subjects, with values near zero (ranging from –0.52 D to +0.46 D). Accommodative responses at near gave similar values pre- (between –1.21 and –2.62 D) and post- (between –1.25 and –2.77 D) exposure to blur, indicating that all subjects showed a lag of accommodation to the 3.00 D stimulus that was unaffected by exposure to blur.

[Figure 3b](#) shows mean data for the emmetropic subjects, where it is clear that the accommodative response to the near target following the blur adaptation period remained unchanged from the initial condition (*t*-paired = –1.48; *p* = .29). In addition, the distance viewing values remained unchanged, with values slightly negative for both the initial (mean ± *SD* = –0.02 ± 0.07 D) and the last (mean ± *SD* = –0.01 ± 0.08 D) conditions.

Myopic subjects also showed stable responses over time for each condition ([Figure 4a](#)). For pre-task distance viewing, the myopes' responses ranged between +0.82 and –0.83 D. For near viewing, all subjects except one showed a

lag of accommodation, with accommodative responses ranging between –1.12 and –3.09 D for the 3.00 D target. Following the 3-min blur exposure, an enhanced accommodative response at near toward more negative values can be observed. Mean data show a significant increase in the accommodation of myopes following blur exposure (*t*-paired = 7.32; *p* < .001) ([Figure 4b](#)). This shift in accommodation remains throughout the 2-min near period and persists during the 1 min of far viewing. No correlation was found between the baseline accommodative response and the accommodative adaptation following blur adaptation (r^2 < 0.01; *t*-paired = 1.72; *p* < .01).

No significant differences in pre-blur baseline accommodation at near were found between the refractive groups (mean emmetropes = 1.98 ± 0.13 D; mean myopes = –2.14 ± 0.12 D) (factorial ANOVA, $F_{1, 38}$ = 0.90; *p* = .35). Analysis of the far (4 m) accommodative response following near viewing shows a myopic shift in the myopic subjects (mean ± *SD* = –0.19 ± 0.07 D) compared to the emmetropes (mean ± *SD* = +0.01 ± 0.03 D). The difference of 0.20 D between the refractive groups was statistically significant (factorial ANOVA, $F_{1, 38}$ = 5.00; *p* = .03).

Analysis of individual data demonstrates ([Figure 5](#)) that all myopes showed an increase in their near accommodative response following blur exposure, while all but one of the
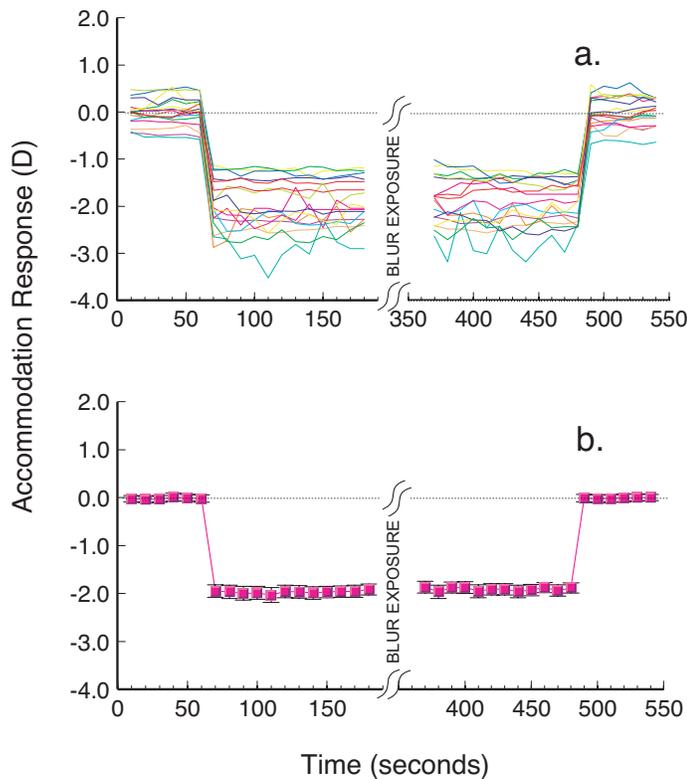

Figure 3a-b. Individual (a) and mean (b) accommodation responses for the emmetropes at each of the conditions tested: far viewing (4 m); initial near condition (0.33 m); near condition following blur adaptation (0.33 m); and far condition (4 m). Error bars show ± 1 SEM.
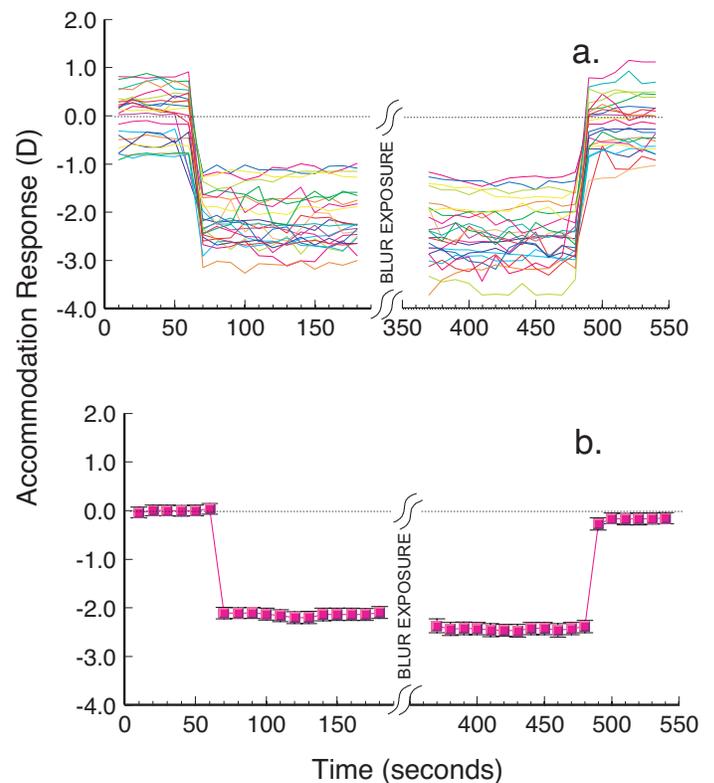
Figure 4a-b. Individual (a) and mean (b) accommodation responses for the myopes at each of the conditions tested: far viewing (4 m); initial near condition (0.33 m); near condition following blur adaptation (0.33 m); and far condition (4 m). Error bars show ± 1 *SEM*.

emmetropes remained unchanged or showed a slight decrease in the accommodative response. In addition, Figure 5 shows mean data from both refractive groups. There was a significant increase (–0.29 D) in the mean accommodative response at near after blur adaptation in myopes (factorial ANOVA, $F_{1, 44}$ = 4.87; p = .01) and no significant change in the accommodative response in emmetropes (+0.06 D) (factorial ANOVA, $F_{1, 32}$ = 0.12; p = .73). The mean shift of accommodation is significantly higher for myopes in comparison to emmetropes (*t*-paired = 6.44; p < .001).
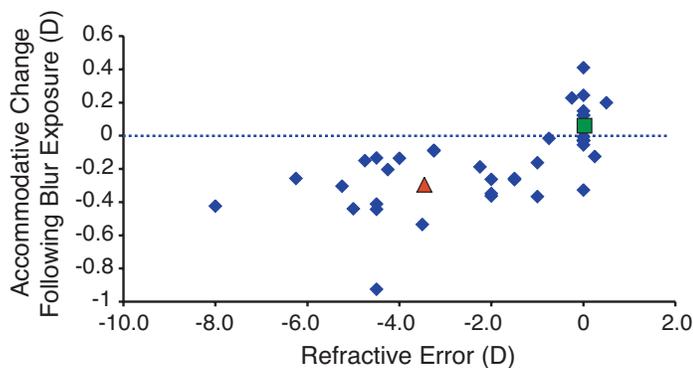

Figure 5. Accommodation change at near (D) following blur exposure as a function of refractive error; individual (◆) and mean grouped data for myopes (▲) and emmetropes (■).

Control experiments

Measurement of accommodative responses during the blur condition (infrared filter)

Figure 6 presents the mean accommodative responses of emmetropes and myopes during 10-s intervals for the eye covered with the IR-transmitting filter (right eye), while the left eye fixated the target throughout this control experiment. These data reveal differences between the responses of emmetropes and myopes during the blur adaptation period. Emmetropic subjects show a stable pattern in their responses for each of the conditions tested, including the blur condition. However, myopic subjects show a progressive increase in their accommodative response over the 3 min blur period. Following the blur condition, the increase in the accommodative response appears to continue during part of the 2-min near measurement period and then regresses to the baseline level of the near accommodative response.

A repeated measures regression model (GEE), which included accommodation, refractive error, time, and the interaction of time with refractive error, revealed that the slopes for emmetropes and myopes were different during the blur adaptation period (p < .001). The model showed that myopes' accommodation increased 0.02 D every 10 s (a total of 0.36 D after 3 min) compared to emmetropes.

Repeated measures ANOVA revealed no significant differences between refractive groups for the baseline near accommodative response ($F_{1, 119}$ = 0.02; p = .78).

Adaptation to open-loop accommodation (dark-focus)

None of the subjects showed accommodative adaptation following the open-loop condition, with mean adaptation values for each refractive group near zero (emmetropes: mean ± *SD* = 0.02 ± 0.07; myopes: mean ± *SD* = –0.01 ± 0.06). Accommodative adaptation values following the open-loop condition were not correlated with the adaptation following the blur condition in the main experiment (r^2 = 0.08; *t*-paired = 2.72; p = .13).

Discussion

Our results reveal for the first time that myopic, but not emmetropic, young adults show an increase in accommodation after experiencing 3 min of adaptation to a near target that has been blurred with a scattering filter. This finding builds on previous work, some from this laboratory, showing differences in accommodation between myopes and emmetropes (Gwiazda et al., 1993; Jiang, 1997; Abbott et al., 1998). The present results are also consistent with previous studies of blur sensitivity, showing that myopes interpret and adapt to blur differently than emmetropes (Rosenfield & Abraham-Cohen, 1999; Oen, Lim, & Cheng, 1994; Wu, Lim, Seet, & Chew, 1997; Thorn, Cameron, Arnel, & Thorn, 1998; Strang, Winn, & Bradley 1998; Turatto et al., 1999). To relate accommodative adaptation to myopia, we suggest that adaptation to blur enhances the gain of the stimulus for accommodation in myopic individuals.
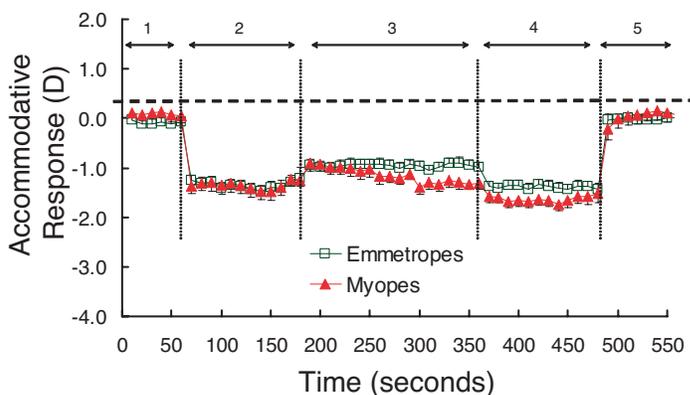

Figure 6. Mean accommodative responses for the eye with the IR transmitting filter at each of the conditions tested [(1) far viewing (4 m); (2) initial near condition (0.33 m); (3) near condition during blur adaptation (0.33 m); (4) near condition following blur adaptation (0.33 m); and (5) far condition (4 m)] as a function of refractive group [emmetropes (□) and myopes (▲)]. Dotted vertical lines represent landmarks for each condition. Error bars show +/- 1 *SEM*.

Accommodation

The finding that myopic children show reduced accommodative responses to negative lens-induced blur has contributed to a new understanding of the role of accommodation in the etiology of myopia (Gwiazda et al., 1993; Gwiazda, Bauer, Thorn, & Held, 1995). Accommodation may be an important factor in mediating the amount of defocus that the retina experiences when near objects are viewed. A consequence of habitual reduced accommodation is that near targets are partially blurred with a hyperopic defocus. Extended periods of such blur may contribute to the development and progression of myopia.

Although the accommodation of myopes is reduced during the progression phase of myopia, (Gwiazda et al., 1993; Jiang, 1997; Abbott et al., 1998), it returns to the level of emmetropes when myopia stabilizes (Gwiazda, et al., 1995). The mechanism underlying myopes' improvement in accommodation during childhood may be the same mechanism that explains our present results. In the present study, no differences in baseline accommodation levels for near viewing were found between the two refractive groups. This is not surprising given that refractive histories, available from approximately half of our subjects, revealed that their myopia was stable.

Blur sensitivity

Although it is not well understood how image blur contributes to eye growth and myopia, perceived blur is known to be influenced by adaptation (Mon-Williams et al., 1998). Myopes often report that their vision is poorer immediately after spectacle removal compared to their performance following a prolonged period without spectacles. Pseudovs and Brennan (1993) investigated this phenomenon and found increased visual acuity in low myopes following a period of uncorrected vision. They suggested that improved VA indicates a sensory adaptation to blur and/or differences in their ability to perceive blur. Data from our first control experiment support this hypothesis. The accommodative changes occurring in myopes during the blur exposure period may reflect a sensory adaptation in those subjects.

Two recent abstracts reported similar improvements in visual resolution after defocus-induced blur adaptation to those found by Pseudovs and Brennan (1993) and showed that adaptation to blur is a robust and long-lasting phenomenon (Portello & Rosenfield, 2002; Rosenfield, Hong, Ren, & Ciuffreda, 2002). Georgeson and Sullivan (1975) hypothesized that everyday vision is chronically altered by a lifetime of experiencing optical degradation from normal visual optics. This experience leads to adaptation in which an observer can perceive suprathreshold high spatial frequencies as having contrast equal to low spatial frequency targets with the same physical contrast, even though high frequencies give much higher thresholds due, in part, to optical degradation. Further suprathreshold equalization of high spatial frequency contrast is reported to occur after a few minutes of adaptation either to defocus caused by positive lenses or to blur induced by the same diffusing filters that are used in the present experiment (Comerford, Thorn, & Chuang, 2002; Hendricks, Comerford, & Thorn, 2003).

In contrast to our results, the only previous study investigating blur-induced adaptation of accommodation demonstrated no significant change in the static accommodative response after three hours of viewing the world through +2.50 D lenses over the subjects' distance refraction (George & Rosenfield, 2002). However, perceptual adaptation did occur. A possible explanation for the discrepant results is that George and Rosenfield (2002) used dioptric blur induced by convex lenses while subjects watched television at 4 m, rather than using scatter blur as in this study. Scatter blur was necessary for the purpose of this study as it does not provide cues for accommodation. Because convex lenses signal the accommodative system to relax accommodation, it is not surprising that accommodation did not increase in the earlier study.

Why does accommodation improve following adaptation to blur in myopia?

The literature reviewed above suggests that myopes, most likely both stable and progressing myopes, show reduced perceptual sensitivity to blur. In addition, accommodation differs between progressing and stable myopes, with progressing myopes showing reduced accommodation that improves with the stabilization of myopia to the same levels shown by emmetropes (Gwiazda et al., 1995). The improvement in accommodation must involve an active long-term adaptation process within the accommodative system itself because perceptual sensitivity to blur continues to be deficient in stable myopes (Rosenfield & Abraham-Cohen, 1999).

Results from the monocular viewing control experiment show that myopes accommodate differently than emmetropes during the blur exposure period. Their accommodative response increases over time, becoming more accurate, whereas the emmetropes' response is stable. This accommodative increase in myopes extends into the post-blur period of near vision. On the other hand, a complete elimination of blur feedback as in the open-loop control experiment leads to no increase in accommodation for either refractive group. This suggests that the accommodation enhancement is specifically due to a blurred stimulus as opposed to no stimulus and that it is the difference in the two refractive groups' use of sensory blur cues that determines the difference in their accommodation adaptation.

The improvement in the accommodative response with the myopia stabilization reported in previous studies may be a consequence of the development of a prolonged blur adaptation mechanism, which results in a habitually more

accurate accommodative response. This mechanism may enhance accommodation in the same way when a myope is presented with the blurred target used in the present study. This strong blur cue would further enhance the accommodative signal and, therefore, the accommodative response. On the other hand, emmetropes habitually have strong sensory cues for accommodation. They have not developed the strong blur adaptation mechanism posited for myopes; and, thus, they show no accommodative adaptation when presented with the blurred target in the present study.

Accommodation adaptation mechanisms may use a change in spatial frequency channel responses or a shift in the stimulus-response range to strengthen blur cues. Blur adaptation may be due to spatial frequency-specific adaptation (Blakemore & Sutton, 1969) in which low frequency channels become fatigued relative to high frequency channels when looking at the blurred text and are thereby prevented from responding to their normal potential. Therefore, in the present study, when the diffusing lenses are removed from in front of the eyes, the high spatial frequency channels may be relatively more responsive than the low frequency channels, and the myopic subjects may perceive primarily high spatial frequency information. However, there is little evidence showing refractive group differences in the balance between high and low frequency channels (Thorn, Corwin, & Comerford, 1986; Comerford, Thorn, & Corwin, 1987; Liou & Chiu, 2001) or strong long-term effects from this type of adaptation. Another possibility is that a long-term increase in the gain of high frequency channels is used to counteract suprathreshold blur and maintain contrast constancy (Georgeson & Sullivan, 1975; Comerford et al., 2002; Hendricks et al., 2003). In addition, myopes may have a shift in the range of stimuli responded to by the accommodative system. Jiang's (1997) model of myopic accommodation includes an elevated accommodative threshold with no change in the stimulus-response gain. An overall stimulus-response function shift may allow myopes to respond to the higher amounts of blur viewed in the present study.

Webster et al. (2002) proposed another possible mechanism mentioned in the Introduction. They proposed that adaptation to blur is consistent with an adjustment that recalibrates the neural response to blur according to the prevailing image, and that it occurs at the level of the visual cortex or higher. At present it is not clear what is causing the increased accommodation following adaptation to image blur in myopes. However, the underlying mechanism may have implications for the understanding of myopia development.

Further experiments

We are currently examining perceptual blur adaptation and accommodation adaptation in parallel in myopes and emmetropes. If the basis for the present result is a poor sensory signal to blur for driving accommodation in myopes, then myopes should demonstrate a greater percep-

tual adaptation to blur under our testing conditions. In addition, to investigate what may be occurring in early stages of myopia development, we propose to study this phenomenon longitudinally in young children who are likely to become myopes as well as in progressing myopes.

Appendix

This movie shows a demonstration of blur adaptation following a protocol similar to that used by Webster et al. (2002) but with a stimulus similar to that used in the present study. The movie shows two images: The bottom image is used as a reference and the top image simulates how the target was perceived by the subjects during our experimental set up, before and after adapting to blur. The amount of blur induced in the top image corresponds to the blur induced by the fogging lenses that were used in this study. The aftereffects are best observed by fixating on the center cross. The image on the top is perceived as sharper following adaptation compared to the reference image at the bottom.

The prevalence of myopia in the under 30 years age group is increasing in many parts of the world.[2,3] Despite this, the aetiology of myopia remains uncertain with both genetic and environmental factors thought to play a role. Genetic factors influence myopia development throughout life, whereas envi-

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Movie simulation.

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