1040-5488/05/8209-0843/0 VOL. 82, NO. 9, PP. 843–849
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Regression of Lid-Induced Corneal Topography Changes After Reading

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ABSTRACT: *Purpose.* The purpose of this article is to investigate the magnitude of lid-induced corneal topography changes as a function of time spent reading and the subsequent time course of regression of these changes. *Methods.* Six young subjects, five myopes and one emmetrope with normal ocular health, participated in the study. Corneal topography of one eye was measured with videokeratoscopy before four reading sessions of 10, 30, 60, and 120 min duration performed on four separate mornings. Corneal topography was again measured at fixed intervals up to 180 min after each reading session. A control trial without reading was also performed on a separate morning. *Results.* All six subjects showed significant changes in corneal topography directly after each of the reading sessions. Longer reading periods caused larger corneal changes. Local instantaneous power changes reached up to 5.95 D (± 2.80 D), whereas refractive power changes in the superior cornea ranged up to 1.26 D (± 0.44) for the 120-min reading trial. The duration of regression of corneal changes showed slower recovery times after longer reading periods. The pattern of regression was similar for all reading times, showing a rapid recovery within the first 10 minutes followed by a slower regression period. *Conclusions.* The length of time spent reading has a cumulative effect on the period over which corneal topography remains altered as a result of lid forces. (Optom Vis Sci 2005;82:843–849)

Key Words: corneal topography, lid force, reading, myopia

The anterior corneal surface makes a significant contribution to the optical characteristics of the eye. Although the shape of the cornea is typically considered to be stable, there are various factors that can alter its short-term and long-term stability.

Lid forces have been implicated in a range of changes seen in corneal topography. Eyelid pressure has long been suspected to cause corneal with-the-rule astigmatism.[1–3] Changes in corneal astigmatism and corneal irregularities have been found in association with chalazion,[4,5] after ptosis surgery,[6] and lid-loading procedures for the treatment of lagophthalmos.[7–9] Studies of transient effects of eyelid pressure on the corneal surface after reading have reported monocular diplopia,[10–17] a shift in the direction of against-the-rule astigmatism,[18] and changes in some higher-order aberrations.[18] There is also evidence that lid-related distortions of the cornea change within seconds during the postblink interval[19] and that eye movements during reading have an effect on the magnitude of the corneal changes.[18]

Diurnal variations of corneal topography have been demonstrated by a number of studies with the cornea becoming slightly steeper throughout the day.[20–23] In a recent study, Read et al.[24] showed that along with a slight steepening, the cornea also undergoes small but significant changes in vertical coma, trefoil, and astigmatism during the day. These changes were considered to be the result of the cumulative effect of eyelid pressure during the day.

Reading is a fundamental aspect of work and study. It is also thought to be a major factor in environmentally induced myopia development.[25–27] Although the exact mechanism of environmental myopia is still not fully understood, emmetropization is thought to be vision-dependent,[28–30] and many theories of myopia development conclude that eye growth is controlled by diminished image quality in myopes compared with emmetropes, often associated with reading.[28,31–34] Changes in corneal topography associated with reading have been shown to be greater in myopes than emmetropes and related to the narrower eyelid apertures of myopes during downward gaze.[35]

The aim of this study was to determine the effects of reading on corneal topography for periods as brief as 10 min and ranging up to 2 h duration. After reading, the time course of recovery of the corneal topography was monitored until the changes were no longer statistically significant.

METHODS

Six subjects, four females and two males, took part in the study. The mean age of the subjects was 24 years, ranging from 21 to 28 years. The right eye of each subject was used for measurements, and five of the subjects were myopic and one was emmetropic. All subjects had best-corrected visual acuity of at least 0 logarithm of the minimum angle of resolution or better. A preliminary slit lamp examination was performed to ensure that all subjects had normal corneal characteristics and no anterior eye disease. All subjects had never worn rigid gas-permeable contact lenses. Soft contact lens wearers were instructed to remove their contact lenses at least 3 d before the study.

The experiment comprised four reading sessions and one control session and was performed on five separate mornings (typically commencing between 8 and 9 AM). The subjects were asked not to perform any significant reading before the experiment began in the morning. The reading trials lasted 10 min, 30 min, 60 min, and 120 min and the order of testing was randomized between subjects to avoid systematic bias. The subjects were seated in an office chair and asked to read a novel. The reading trials were intended to simulate a typical reading task and therefore subjects were encouraged to adopt a natural reading posture during the trial.

The Keratron videokeratoscope (Alliance Medical Marketing, Jacksonville, FL) was used for the corneal topography measurements. Six videokeratographs were taken at each measurement session. Baseline corneal topography data was measured before reading and again at 0, 2, 4, 6, 8, 10, 15, 20, 25, 30, 45, 60, 75, 90, 120, 150, and 180 min after reading. For the 10-min reading trial, measurements were taken up to 60 min postreading, because pilot studies had indicated that this was likely to be sufficient time for complete corneal recovery. Between the postreading measurement sessions, the subjects were asked not to perform any reading, writing, or to use a computer. As a control experiment, the subjects' corneas were measured on a separate morning at time intervals of 2, 60, 120, and 180 min after the first measurement was taken. Again, the subjects were asked not to read, write, or to use a computer before and between the measurement sessions.

Using a high-resolution digital camera, a photograph of each subject's eyelid position in primary gaze was taken at the first experimental session. The camera was mounted on a tripod and the subject's head was positioned in a headrest. A second photograph of the subjects' eyelid position was taken while reading holding the digital camera between the subject and book. Eyelid position during reading was overlaid on the corneal topography and changes in topography compared with lid position. The methods for this analysis have been described previously.[18]

Each subject was asked to report subjective vision changes such as monocular diplopia associated with reading. Before and after every measurement session, the left eye was covered and the subjects were instructed to look at optotypes of 0.4 logarithm of the minimum angle of resolution size on a Bailey-Lovie test chart. The laboratory was darkened to mesopic levels to maximize natural pupil size and the test chart was illuminated. The examiner recorded the subject's description of vision quality.

Corneal height, refractive power, and instantaneous power data were exported from the videokeratoscope for subsequent analysis. The six videokeratoscopes taken per measurement session were averaged according to a method outlined in Buehren et al.[18] To investigate changes in the refractive and instantaneous power (before reading versus postreading), difference maps were calculated and significance maps (i.e., maps showing regional statistical significance of changes) were created for a 7-mm diameter (centered on the videokeratoscope axis). To analyze the changes in corneal (refractive and instantaneous) power after reading, a meridian analysis was performed in the 90° to 270° (vertical) meridian, because this meridian shows the greatest changes in topography associated with eyelid forces.[18] The greatest change along the 90° to 270° meridian in each difference map was derived based on the highest positive or negative refractive power value (Fig. 1).

One-way repeated-measures analysis of variance (ANOVA) were used to evaluate the significance of changes in instantaneous power, the root mean square error (RMSE) of change in topography height, and the location of the maximum change in topogra-

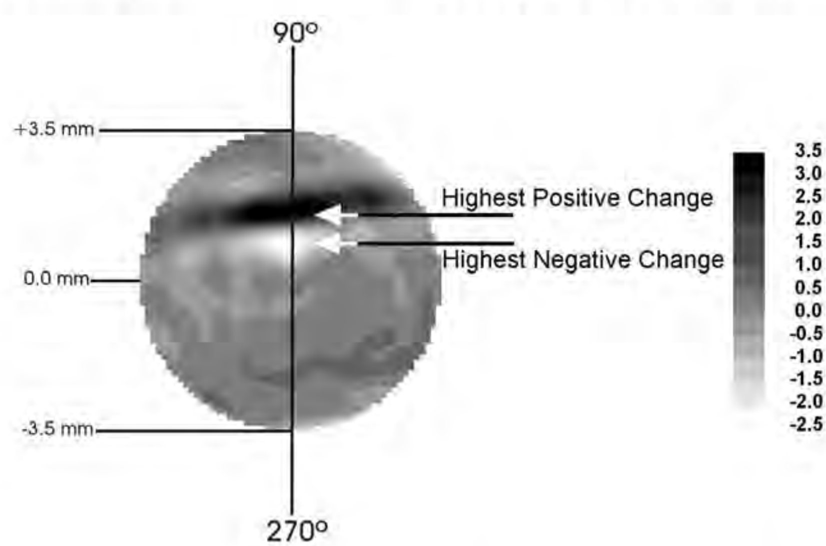

FIGURE 1.

Locating the highest change of power in the instantaneous power difference map along the 90° meridian. Changes in corneal topography primarily occurred in the superior half of the cornea and were correlated with upper eyelid position during reading. The highest positive change and negative change in instantaneous power were measured along the 90° meridian from the center of the map up to a distance of 3.5 mm.

phy versus the amount of time spent reading. Two-way repeated-measures ANOVAs were conducted to study the regression of refractive power postreading versus the amount of time spent reading and the time delay postreading.

To estimate the impact of topography changes on clinical refraction, the refractive power maps were used to analyze the best-fit spherocylinder as well as the RMSE from the best-fit spherocylinder for a 4-mm diameter. Power matrices were used to average individual best-fit spherocylinders and to calculate the corneal changes in sphere, cylinder, and astigmatic axis pre- versus postreading. A multivariate test (Hotelling's T^2) was used to test the significance of the changes in corneal best-fit spherocylinder.

RESULTS

Instantaneous Power

All subjects showed significant changes in the instantaneous power in the superior cornea after reading. Analysis of digital photography confirmed that the changes showed good correlation with the upper eyelid margin position during reading. Changes in the inferior cornea as a result of the lower eyelid margin appeared less often and were of lesser magnitude. The changes in instantaneous power of one representative subject immediately after reading are presented in Figure 2. The instantaneous power difference maps (Fig. 2, left column) show that an increase in the time spent reading increases the bandlike changes of the corneal topography. The corneal changes after reading are highly significant ($p < 0.001$) as shown in the significance maps (Fig. 2, right column).

The group average regression of changes in instantaneous power in the 90° meridian for all four reading conditions is shown in Figure 3. The group average of the maximum difference in instantaneous power (i.e., "maximum positive change" minus the "maximum negative change") along the 90° meridian, within a 7-mm corneal diameter, was 5.95 D (± 2.80 D) after 120 min of reading, 4.14 D (± 1.21 D) after 60 min of reading, 4.48 D (± 1.93 D) after 30 min of reading, and 2.87 D (± 0.85 D) after 10 min of reading. These changes in instantaneous power were statistically

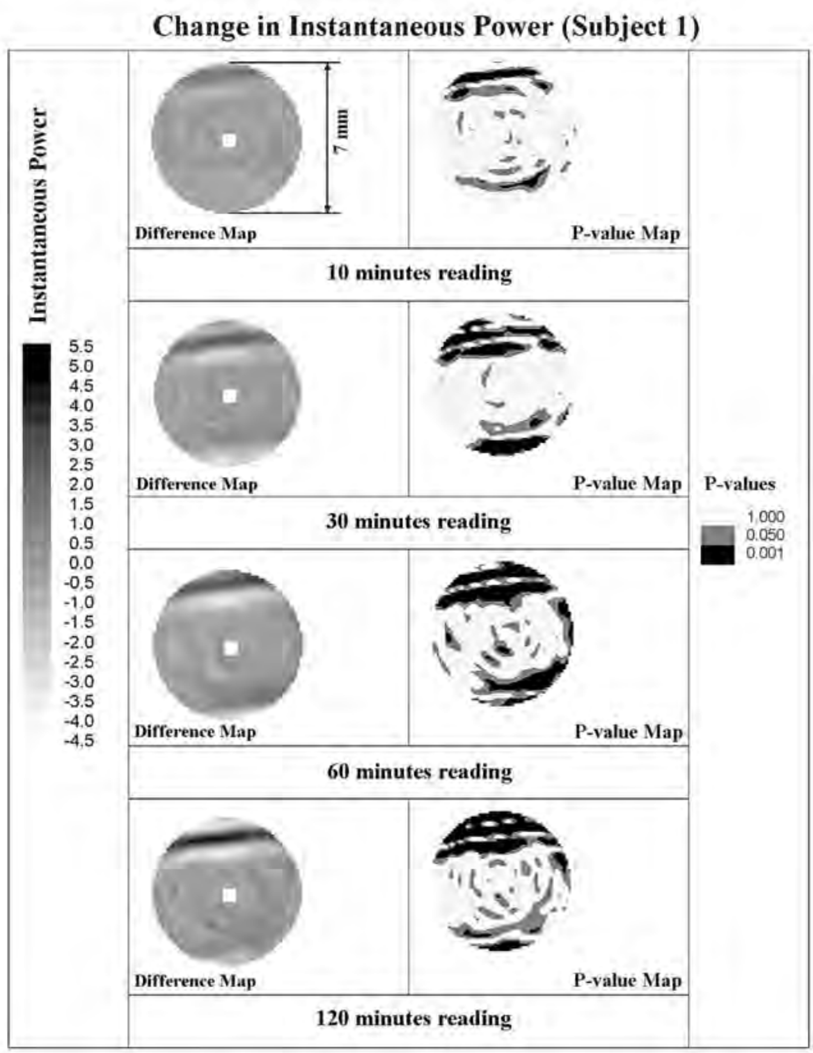

FIGURE 2.

Instantaneous power difference and significance maps of a representative subject (subject 1) immediately after the four reading trials (10, 30, 60, and 120 min duration). The location of the eyelid related can be clearly seen in the superior cornea after each trial. The magnitude of changes is related to the duration of reading, and this can also be seen in the statistical significance maps, in which t-tests are performed on the magnitude of change at each location within the maps.

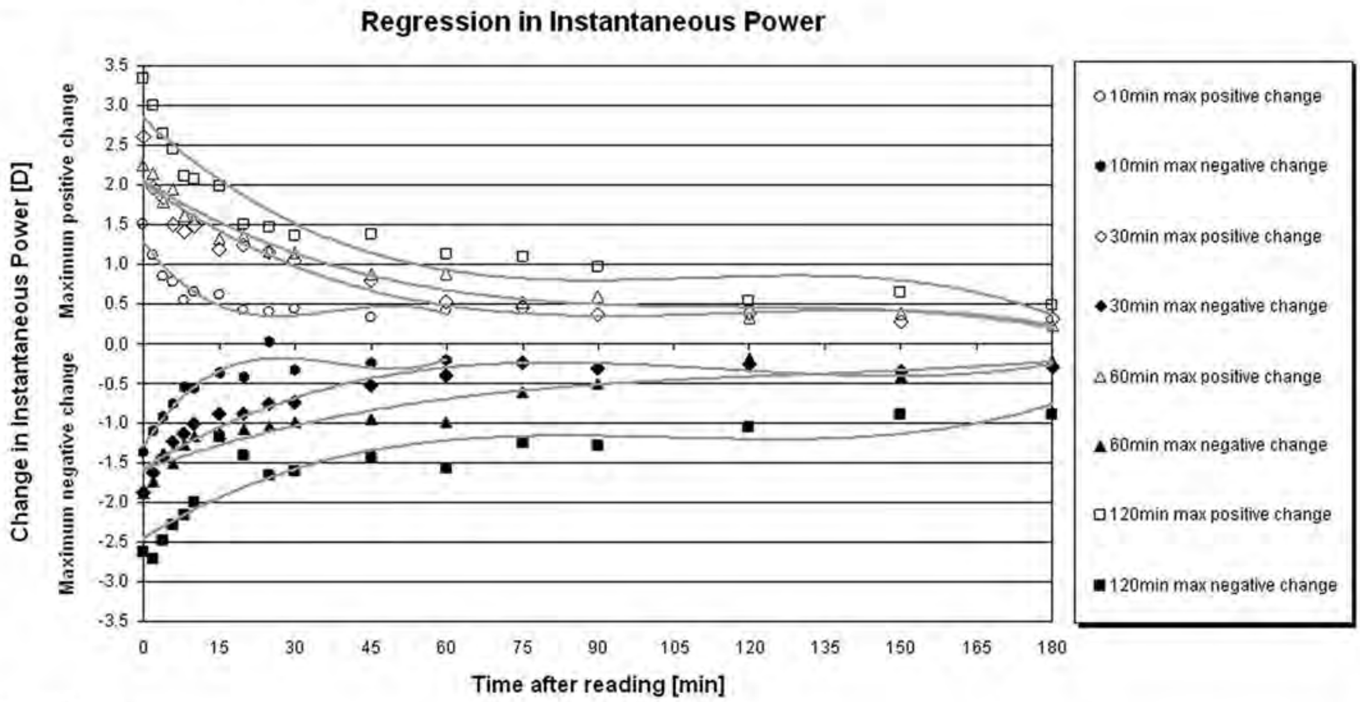

FIGURE 3.

Regression of instantaneous power changes after reading trials (10 to 120 min) in the 90° meridian. The maximum positive and negative power changes show similar magnitudes immediately after reading and similar regression patterns.

significant immediately after reading for all of the reading trials (10 min up to 120 min) compared with the prereading cornea (t-tests all $p < 0.01$). The regression of these instantaneous power changes over the time up to 180 min postreading were also all statistically significant using a one-way repeated-measures ANOVA (all $p < 0.001$).

The location of the maximum positive and negative changes in instantaneous power varied depending on the location of the subject's upper eyelid margin during reading. The maximum positive power change typically occurred around 2.5 mm above the center of the topography map (vertex normal), whereas the maximum negative power change typically occurred around 1.8 mm above the center of the topography map.

Refractive Power

Directly after reading, significant changes in refractive power were also found for all reading trial conditions (from 10 min up to 120 min reading) along the 90° meridian in the region up to 3.5 mm from the center of the map. The highest difference in local refractive power was found after 120 min reading with a group mean difference in power of 1.26 D (± 0.44 D). After 60 min of reading, the difference was 0.96 D (± 0.31 D), after 30 min it was 0.92 D (± 0.28 D), and after 10 min it was 0.76 D (± 0.42 D). By contrast, the control condition (no reading) showed a group mean refractive power difference along the 90° meridian of 0.32 D (± 0.17 D). These natural variations in refractive power reflect common aberrations such as spherical aberration or vertical coma.

The regression in corneal refractive power changes after the reading and control trials are presented for the 90° meridian in Figure 4. All reading trials (10 min up to 120 min) cause an increase in refractive power variation along the 90° corneal meridian. These changes show gradual regression to levels similar to the control condition, with longer reading trial conditions requiring longer regression times. A two-way repeated-measures ANOVA was performed on the difference of refractive power for the first 60 min after reading. It showed that the length of time spent reading had a significant effect on the magnitude of refractive power change ($p = 0.005$), and that the time period after reading showed significant regression of refractive power changes ($p < 0.001$). However, there was no significant interaction between the length of time spent reading and the regression of refractive power changes ($p = 0.24$). This suggests that the rate of regression of power changes was independent of the length of time spent in prior reading.

The control condition (no reading) showed a slight but systematic increase in refractive power variation along the 90° throughout the 180-min observation period (Fig. 4). These findings, although surprising, are consistent with similar data reported by Read et al.,[24] who followed diurnal corneal topography changes over the course of 3 d.

Spherocylinder

A statistically significant change in the best-fit spherocylinder (i.e., corneal spherocylinder) after reading was found in five of the six subjects for one or more of the reading trials. One subject did not show significant changes after any of the reading tasks (subject 3), although after the 60-min and 120-min reading trials, borderline significance was found (Hotelling T^2 $p = 0.065$) for both conditions. Several subjects showed significant changes in spherocylinder after the 10-min, 30-min, or 60-min reading task, whereas four of six showed significant change after the 120-min reading task (subjects 1, 2, 4, and 5, Hotelling T^2: $p < 0.05$). The highest

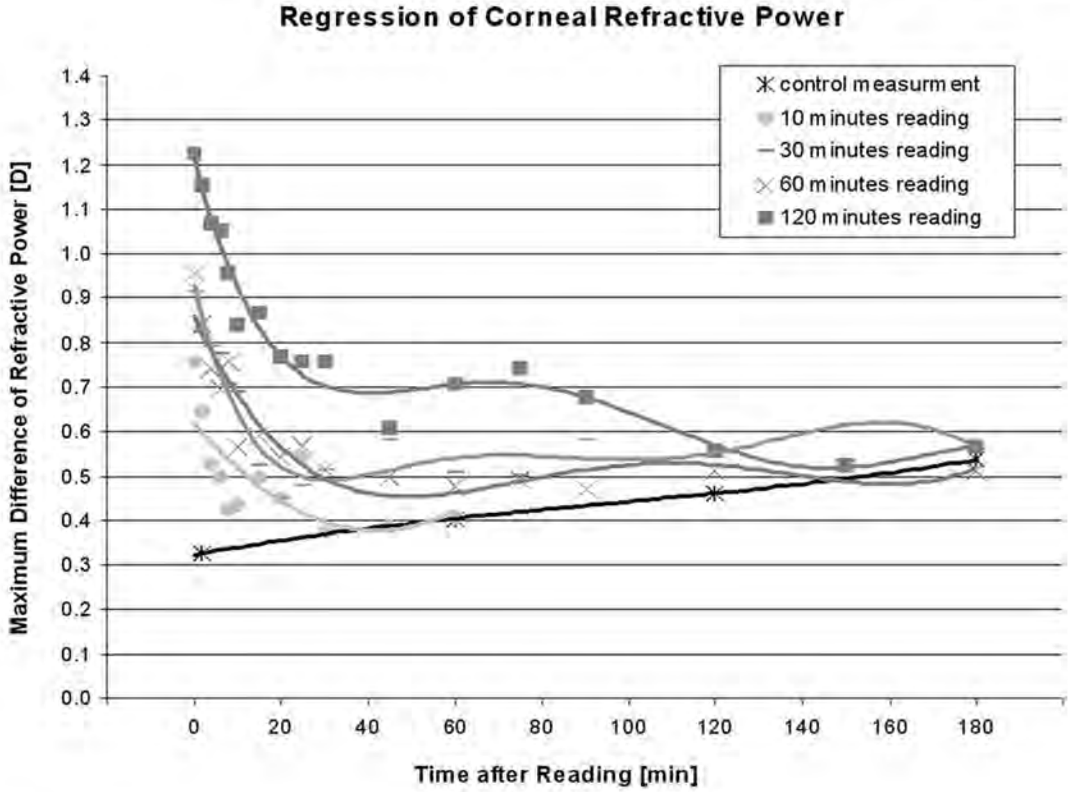

FIGURE 4.

Regression of corneal refractive power changes after the four reading trials (10 to 120 min). The y axis is the maximum difference in refractive power along the 90° meridian. The control condition involved no substantial visual tasks.

change in corneal spherocylinder occurred directly after 120 min of reading in subject 4 (+0.43/−0.64 × 105).

Root Mean Square Error

The group average corneal RMSE (i.e., RMSE away from the best-fit corneal spherocylinder) after 120 min of reading was significantly increased compared with the baseline corneal RMSE (increase was 0.11 D, $p = 0.03$). The increase after 60 min of reading was 0.13 D ($p = 0.10$). No significant changes were found for the 10-min or 30-min reading trials.

Subjective Vision Quality

Three of the six subjects reported monocular diplopia after reading with vertical displacement of the secondary image. The subjects were optometry students or research staff who could provide detailed descriptions of these visual phenomena. One subject noted a diplopic appearance of optotypes in the first 2 min after the 60- and 120-min reading trials and reported slightly blurred vision up until 90 min postreading (subject 5). Subject 2 reported minor vertical diplopia of optotypes until 20 min postreading, after the 10- and 30-min reading task but not after the longer reading periods. After 60 and 120 min reading, subject 3 noticed significant vertical diplopia, which remained until about 60 min postreading.

DISCUSSION

In reading gaze position, the eyelids cause changes in corneal topography that are related in magnitude to the length of time spent reading. That is, longer periods of continuous reading produced greater corneal topography changes. The regression of these topographic changes showed a similar pattern after different reading periods with a significant decline of changes within the first 10 min followed by a slower regression thereafter. After 10 min of reading, the corneal topography changes were largely gone within 10 min, whereas after 120 min of continuous reading, it took approximately 120 min for the topography changes to disappear. As a generalization, the amount of time for regression of the corneal changes to baseline levels required approximately the same amount of time as the person spent continuously reading. Because it is uncommon for a person to read continuously for 2 h, as they did in our experiment, it would be interesting to investigate the cumulative nature of multiple shorter periods of reading, as might typically happen with children in a classroom situation. Read et al.[24] have recently shown diurnal changes in the corneal optics of adults whose work involves significant reading.

The magnitude and location of the corneal topography changes we measured are consistent with those previously reported by Buehren et al.[18,35] These topography changes closely follow the location of the eyelid margin during reading gaze. The localized increase and decrease of corneal radius in a horizontal band suggests that corneal reshaping is occurring as a result of the force of the eyelid margin. The process of orthokeratology may reflect a similar underlying mechanism of topographic change, but there is still no clear consensus on the exact anatomic nature of these changes.[36–38]

Because the topographic changes originate from the region of the cornea near the eyelid margin, it is possible that local changes in the tear film could also arise in this region of the ocular surface.

However, it seems unlikely that any tear-related changes would persist in this region after a few natural blinks.

Reports of transient corneal deformation after reading and other forms of pressure are common in the literature. Bowman et al.[10] reported a case of corneal distortions after a 75-min reading period that recovered nearly completely after 1 hour postreading. Carney and Clark[39] studied corneal deformation and recovery after using tonometer pressure for 30 s that generally disappeared within 10 min. Mandell and Helen[40] studied corneal deformation caused by digital pressure that resolved within minutes. Knoll[15] reported his personal experience of corneal deformation after reading that required several hours recovery time (provided no further near work was undertaken). His description of vertical diplopia after reading closely matched the visual symptoms reported by three of the six subjects in this study and is consistent with optical changes primarily occurring along the vertical meridian of the cornea. Collins et al.[41] have analyzed the impact of reading on the retinal image and have shown substantial changes along the vertical meridian.

The regression of corneal changes associated with eyelid pressure in this study can be compared with other studies investigating corneal recovery after orthokeratology[42,43] or cosmetic tinted contact lens wear.[44] Voetz et al.[44] showed recovery of corneal deformation lasting up to 3 hours after 1 hour of cosmetic tinted contact lens wear. Horner et al.[42] found corneal topography regression after orthokeratology of between 30% and 50% recovery per hour after 4 and 1 hour of lens wear, respectively. Swarbrick et al.[43] concluded that most corneal regression occurred within an hour after 10 min wearing of orthokeratology contact lenses.

In summary, the amount of time spent in reading significantly influenced both the magnitude of corneal changes and the duration of recovery of the cornea to its prereading state. The topography of the cornea, and consequently the optical properties of the eye, is therefore sensitive to the prior reading tasks that have been undertaken.

Received November 25, 2004; accepted April 13, 2005.

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