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ORIGINAL ARTICLE

The Effect of Accommodation on Ocular Shape

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ABSTRACT: *Purpose.* Ocular shape is altered in myopia, and accommodation during nearwork is a proposed risk factor for myopia. Using relative peripheral refractive error (RPRE), ocular shape was assessed before, during, and after a period of sustained nearwork to determine whether accommodation affects ocular shape. *Methods.* Measurements of RPRE at 30° in the nasal visual field were obtained using the spherical equivalent calculated from Canon R-1 autorefraction. The RPRE of 41 young adults was measured on two separate occasions separated by at least 1 week to assess RPRE repeatability. Later, the RPRE of 22 young adults was measured at a 0 D accommodative stimulus and then at a 3 D stimulus level at 0, 1, and 2 h during which subjects performed sustained nearwork at 33 cm. After 2 h of nearwork, subjects had RPRE measured at prescribed time intervals over a 1-h period in which they looked in the distance (0 D stimulus). *Results.* The measurement of RPRE had adequate repeatability (mean difference ± SD, −0.05 ± 0.35 D) with ±0.68 D as the 95% limits of agreement. The onset of accommodation produced an immediate hyperopic shift of RPRE relative to baseline (+0.37 ± 0.44 D; $p = 0.0007$), indicating that ocular shape had become more prolate. This shape remained unchanged after 1 h of sustained accommodation (RPRE difference from baseline, +0.25 ± 0.55 D; $p = 0.04$) and then returned to baseline dimensions after 2 h of accommodation (RPRE difference from baseline, +0.11 ± 0.39 D; $p = 0.21$). At the 0 D stimulus level one minute after the period of nearwork, RPRE became more myopic relative to baseline (RPRE difference from baseline, −0.28 ± 0.50 D; $p = 0.016$). Ocular shape returned to baseline dimensions after 45 min of accommodative relaxation. *Conclusions.* Accommodation induced the ocular shape to become more prolate. The opposite occurred after accommodation was relaxed, namely a change toward a more oblate ocular shape. The transient nature of these changes suggests that tension on the choroid and choroidal hysteresis may play a role in influencing ocular shape. (Optom Vis Sci 2002;79:424–430)

Key Words: myopia, refractive error, accommodation, ciliary muscle

Ocular shape is associated with refractive error, with myopic eyes exhibiting a prolate contour (i.e., having a longer axial length than equatorial diameter) and hyperopes an oblate contour (i.e., having a broader equatorial diameter than axial length).[1–4] In addition, elevated rates of myopia are associated with increased amounts of cumulative nearwork exposure. Utilizing one's attained educational level,[5–7] measured intelligence, or the nature of one's occupation[4, 8, 9] as indices of the degree of nearwork activity, several studies have shown that visual nearwork is related to myopia. Attempts to relate these two associations suggests that visual nearwork might therefore be associated with an elongated ocular shape. The present study investigates whether visual nearwork activity might result in any ocular shape distortion.

Additional motivation for this study comes from data on refractive components and the changes they undergo during ocular development. Among the studied components, the crystalline lens has been the subject of considerable discussion. Mutti et al.[10] have stated that "the importance of the lens in maintaining emmetropia during childhood suggests that development of the crystalline lens may provide insight into how emmetropia may be lost with the onset of myopia." Indeed, a recent longitudinal study of 822 children aged 5 to 14 years has shown that thicker crystalline lenses were associated with more hyperopic relative peripheral refractions and thus associated with prolate-shaped myopic eyes within a given refractive error group.[4] This finding is of interest because lenticular thinning during development ceases near 10 years of age,[11] and the prevalence of myopia has been shown to increase sharply at age 10 years.[10] As a result, Mutti et al.[4] have proposed a model that suggests failure of the crystalline lens to thin amid continued growth of the globe may create tension within the lens, ciliary body, and choroid. They asserted that the tension at the equator ultimately restricts ocular growth within the equatorial plane and subsequently accentuates axial elongation leading to the prolate ocular shape typical of myopia.

For lenticular restriction to be important in this model, the tension must be transmitted to the equator of the globe to create distortion.[4] Microscopic analysis has shown that ciliary muscle elastic tendons make extensive connections with the elastic layer of Bruch's membrane.[12] These connections with the choroid result in an anterior displacement of the retina, presumably from increased choroidal tension, during accommodation.[13, 14] These connections may be sufficient to transmit tension from the crystalline lens through the ciliary muscle to the choroid. The choroidal stretch from accommodation also creates a negative pressure in the suprachoroidal space of up to3 mm Hg.[15, 16] As a result, the surrounding band of extraocular muscles may relieve this negative pressure and contribute to ocular shape distortion.[4]

Similarly, equatorial restriction during development may produce ocular distortion in myopia. The present study used nearwork-induced accommodation in nonpresbyopic adults to replicate choroidal tension and equatorial restriction presumed present in emerging myopic eyes during childhood. The intent of the present study was to investigate whether sustained accommodation and presumed choroidal tension results in any measurable distortion of ocular shape, to help determine whether it is plausible that tension within the lens, ciliary body, and choroid during development could induce ocular shape distortion in the development of juvenile myopia.

Assessment of ocular shape has been measured optically using peripheral refraction[2, 3, 17] and, more recently, as the relative change in the spherical equivalent refractive error with movement from an axial to a peripheral angle of measurement.[4, 18] By subtracting the spherical equivalent refraction in primary gaze from the spherical equivalent refraction in 30° peripheral gaze, relative peripheral refractive error (RPRE) has been used to describe ocular shape. A positive RPRE value identified an eye as prolate, and a negative value indicated an oblate ocular contour. The validity of peripheral refraction as a measure of ocular shape has been evaluated in computer simulations, with spherical equivalent peripheral refractive error yielding valid retinal coordinates (within 0.50 D or 0.20 mm) for field angles up to 40°.[19] It is robust to subject variation of corneal toricity, lens shape, lens tilt, and gradient index properties of the lens.

METHODS

Two phases of research were conducted. The repeatability of RPRE measurements using the Canon R-1 autorefractor was established in the first phase, whereas the purpose of the second phase was to determine whether ocular shape becomes altered during sustained accommodation using RPRE measures. Additionally, the recovery of the eye from any nearwork-induced shape change was measured over time. For both phases, autorefraction was performed using the Canon R-1 (Canon U.S., Lake Success, NY; no longer manufactured). The open view design of the R-1 allowed the subject to view accommodative stimuli through the instrument. The Ohio State University Institutional Review Board approved both phases, and written informed consent was obtained from all subjects according to the Declaration of Helsinki.

Repeatability

Prospective subjects were questioned and screened for exclusion under the following criteria: (1) presence of active eye pathology, (2) history of refractive surgery, (3) current rigid contact lens wearer, and (4) right eye refractive error (spectacle wearers) or over-refraction (soft contact lens wearers) more myopic than −4.00 D sphere, more hyperopic than +3.00 D sphere, or astigmatism more than −1.00 D. Any subject more myopic than −4.00 D was corrected in soft contact lenses. Rigid contact lens wearers and subjects with prior refractive surgery were excluded to ensure that subjects possessed a smooth optical surface over their entire cornea for autorefraction through the central and midperipheral cornea. Refractive error ranges were limited by the length of the Badal track.

Forty-one subjects aged 19.5 to 36.6 years (mean ± SD, 25.4 ± 2.8 years) were enrolled. This sample was 48.8% female. Subjects' right eye spherical equivalent refractive error ranged from +1.13 to −6.31 D (−3.06 ± 1.92 D). The subjects attended two visits separated by at least 1 week, and the same protocol was performed at each visit. Subjects wearing soft contact lenses were tested with their lenses in place and wore the same lenses to both visits. Spectacle wearers were tested without their correction at both visits. Only the right eye was tested.

At each visit, the subject monocularly fixated a reduced 20/50 Snellen target (angular subtense at the eye, 12.5') with a luminance of 50.4 cd/m^2 through a +4.00 D Badal lens. The target was placed on a track allowing for the adjustment of target distance to relax accommodation yet provide maximum clarity to hyperopic and myopic subjects. The target was positioned at the subject's nonaccommodating far point. At least 20 autorefraction measurements were then made while the subject fixated the target in primary gaze (Fig. 1).

Immediately after measurement, the track was rotated 30° and placed before a front surface mirror on the patient's right (Fig. 1). Subjects were instructed to turn their eyes to their right (the tested eye turned temporally) and look into the mirror to find the backward letters. The distance between the Badal lens and the subject's eye and the chart location on the track remained constant in each condition. Once the subject responded that the letters were back-

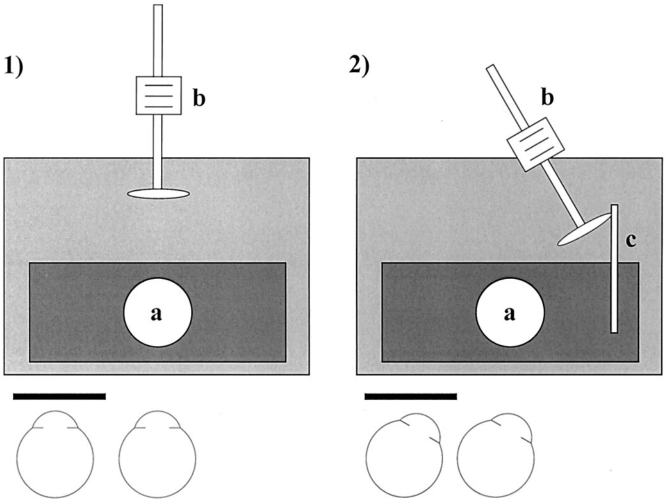

FIGURE 1.
Diagram of the experimental apparatus viewed from above, in which 1a and 2a represent the objective lens of the Canon R-1 autorefractor, 1b and 2b represent the Badal track with letter target, and 2c represents the front surface mirror.

ward and the eye was observed to be steady in the television monitor of the autorefractor, at least 20 measurements were collected.

For each direction of gaze in which data were collected using the R-1, approximately 20 measurements were initially taken and later edited to a total of 10 valid autorefraction readings. Editing for validity was performed using a predetermined editing criteria applied in a systematic manner. Instrument-generated "ERROR" messages were eliminated first. Second, any measured sphere or cylinder value that deviated by more than ±5.00 D from the respective mode for each subject was eliminated. The remaining measurements were edited through one-by-one elimination in an alternating first-to-last sequence, until 10 valid autorefraction readings remained (i.e., the first valid reading was eliminated, then the last, then the second valid reading, then the second-to-last, etc.). The spherical equivalent for each of the 10 autorefraction measurements was then calculated, and the median spherical equivalent from the 10 measurements was determined. With data in this form, the RPRE for each subject was calculated as the median spherical equivalent of the primary-gaze autorefraction subtracted from the median spherical equivalent peripheral-gaze autorefraction. From these values, primary-gaze, peripheral-gaze, and RPRE repeatability between the two visits were assessed.

Accommodation and RPRE

Exclusion criteria were the same as for the repeatability phase except for (1) right eye refractive error (spectacle wearers) or over-refraction (soft contact lens wearers) more myopic than −1.00 D sphere, more hyperopic than +3.00 D sphere, or astigmatism more than −1.00 D, (2) presence of amblyopia or strabismus, (3) presence of any accommodative disorder. Exclusions were made for refractive error because of limitations of the Badal track to stimulate 3 D of accommodation in subjects with high refractive errors or over-refractions. Any subject more myopic than −1.00 D was corrected in soft contact lenses.

Twenty-two subjects aged 19.7 to 36.9 years (25.7 ± 3.3 years) were enrolled as subjects. Based on the standard deviations from the repeatability study, we estimated that we could detect differences in RPRE as small as 0.24 D at this sample size with $\alpha = 0.05$ and $1 - \beta = 0.90$. This sample was 40.9% female. Subjects' right eye spherical equivalent refractive errors ranged from −0.41 to −6.31 D (−3.48 ± 1.76 D). Subjects wearing soft contact lens corrections ($N = 17$) performed all near work and had all measurements taken with the lenses in place. One subject wore spectacles and was autorefracted without wearing her glasses; however, the correction was worn during the visual tasks of the protocol. Only the right eyes were tested.

At the onset of data collection, RPRE measurements were collected to quantify the subject's ocular shape in the absence of accommodation. These baseline autorefractions were conducted using instruments and protocol identical to those described in the repeatability phase (Fig. 1). The reduced Snellen target resting on the track was then moved from the subject's established nonaccommodating far point toward the subject to induce 3 D of accommodation. With this set-up, separate primary-gaze and peripheral-gaze autorefraction was performed while the subject maintained clear fixation of the target now positioned to induce 3 D of accommodation. At least 20 readings were taken in each of these respective gazes.

The subject was then instructed to perform a constant nearwork visual task maintained at 33 cm from the spectacle plane for a duration of 2 h, while making every effort to maintain clear visual focus on the task without interruption. The subject was permitted to vary the nearwork task (i.e., reading books/magazines, video game use) to avoid boredom but was monitored to ensure that the prescribed 33-cm working distance was maintained. To assist proper maintenance of the working distance, each subject was fit with a string of 33 cm length attached at one end to the nearwork target and attached at the other end to plastic spectacles with no lenses in the eyewires. The subject wore the restraining spectacles for the duration the near visual task.

Midway through the nearwork task after 1 h of constant accommodation, at least 20 readings were again taken in primary gaze and 10 readings in peripheral gaze while the subject maintained focus on the Snellen target inducing 3 D of accommodation. Throughout the entire protocol, strict attention was given to ensure seamless transition between viewing the nearwork target of regard and the temporary nearwork Snellen target used during autorefraction measurements.

At the conclusion of the second hour of nearwork, at least 20 autorefraction readings were again taken in primary gaze and 20 readings in peripheral gaze while the subject maintained focus on the target assigned for 3 D of accommodation. These data were collected in the same way as described for the 1-h nearwork data collection. The subject was then instructed to maintain a clear view of a distant target for 1 h to place the accommodative system at rest. A television was placed 20 feet from the subject to serve as a distant target. At seven prescribed time intervals during this hour of distant viewing, at least 20 autorefraction readings were taken in primary gaze and 20 readings in peripheral gaze under the previously described 0 D accommodative stimulus conditions. These readings took place 1, 2, 5, 15, 30, 45, and 60 min after the onset of the subject's distance viewing.

For each direction of gaze and accommodative stimulus level in which autorefraction was performed, approximately 20 measurements were initially taken and later edited to a total of 10 valid autorefraction readings. Editing was conducted using the same criteria previously described in the repeatability phase. The spherical equivalent for each of the 10 autorefraction measurements was then calculated, and the median spherical equivalent from the 10 measurements was determined. With data in this form, the RPRE for each subject was calculated as the median spherical equivalent of the primary-gaze autorefraction subtracted from the median spherical equivalent peripheral-gaze autorefraction. Changes in RPRE as a function of time were analyzed using paired t-tests.

The conversion between diopters of RPRE and millimeters of axial length has not been quantified. However, we would estimate that 1 mm of peripheral shape change would equal between 2.5 and 3.5 D based on calculations of the errors in diopters and millimeters at 30°[19] and in schematic eye models.

RESULTS

Repeatability

Repeatability results are shown in Table 1. RPRE had 95% limits of agreement that were comparable to primary-gaze refractive error. Repeatability of the RPRE measurement was also ana-

TABLE 1.

Analysis of repeatability results for primary-gaze autorefraction, peripheral-gaze autorefraction, and RPRE.

Variable	Mean Difference (D)	t_{40} Value	p Value	SD (D)	95% LoA (D)
Primary-gaze autorefraction	0.01	0.30	0.76	±0.26	±0.51
Peripheral-gaze autorefraction	−0.04	0.70	0.49	±0.37	±0.73
RPRE	−0.05	0.97	0.34	±0.35	±0.68

lyzed by a categorical classification of eye shape between trial 1 and trial 2. Of the 22 eyes identified as a prolate shape (positive RPRE value) by RPRE in trial 1, 21 of the eyes were also found to be prolate by RPRE measurements in trial 2. Furthermore, 19 eyes were identified as being oblate (negative RPRE value) in trial 1, and 20 eyes were found to be oblate by RPRE measurements in trial 2. Agreement was relatively robust with a kappa equaling 0.95 with a 95% confidence interval of 0.86 to 1.00.

Accommodation and RPRE

Subjects' mean RPRE at baseline was +0.27 ± 1.58 D. Onset of nearwork at the 3 D stimulus level immediately produced a more positive RPRE value (+0.64 ± 1.65 D), representing a significant hyperopic shift in RPRE from baseline (change from baseline, +0.37 ± 0.44 D; $p = 0.0007$). This positive shift in RPRE indicated that ocular shape had become more prolate relative to baseline. At the completion of 1 h of sustained nearwork, mean RPRE was +0.52 ± 1.59 D, a value still significantly more hyperopic (+0.25 ± 0.55 D; $p = 0.04$) than baseline. Measurement of RPRE at the completion of the second hour of accommodation revealed that RPRE was +0.37 ± 1.59 D, indicating that the eye had returned to baseline dimensions (RPRE difference from baseline, +0.11 ± 0.39 D; $p = 0.21$). Fig. 2 illustrates these changes.

This regression toward baseline RPRE raises the issue of whether there might have been a decrease in accommodative response over time. The subjects' mean accommodative response at onset of the 3 D stimulus nearwork task was 2.18 ± 0.49 D, with 19 subjects displaying between 1.50 and 3.00 D of accommodation. The subjects' accommodative response remained unchanged throughout the 2 h of nearwork compared with the accommodative response at the onset of the 3 D task (mean accommodative response, 2.29 ± 0.45 D; $p = 0.066$ at hour one; mean accommodative response, 2.26 ± 0.39 D; $p = 0.15$ at hour two). Consequently, there was no evidence of change in subjects' accommodative response during the period when RPRE shifted toward baseline.

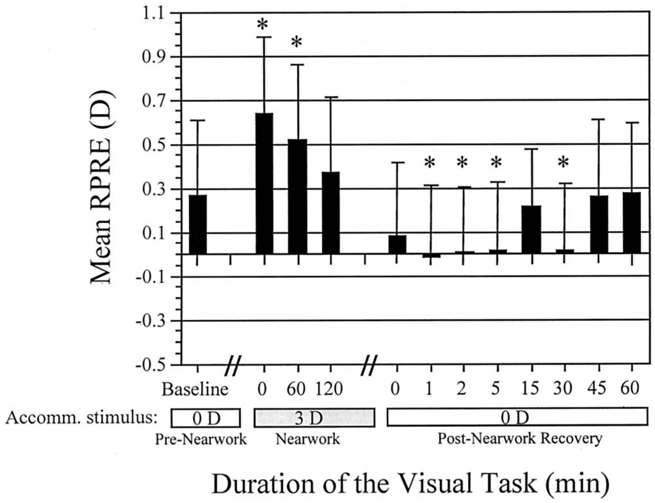

FIGURE 2.

Mean RPRE as a function of time under varied accommodative stimuli. Asterisks indicate an RPRE value that is statistically different from the baseline.

After 2 h of the 3 D accommodative task, the subjects fixated a distant target to relax accommodation. At cessation of accommodation, RPRE measurements were immediately recorded and found to resemble the baseline RPRE (0.08 ± 1.58 D; $p = 0.096$). However, after 1 min of accommodative relaxation, the mean RPRE was −0.01 ± 1.53 D. This represented a significant myopic shift in RPRE (−0.28 ± 0.50 D; $p = 0.016$) relative to baseline and indicated that ocular shape had become less prolate than the baseline contour. This less prolate shape remained present and unchanged in magnitude at the 2-, 5-, and 30-min postnearwork measures with RPRE differences from baseline equaling −0.26 ± 0.47 D ($p = 0.02$), −0.25 ± 0.52 D ($p = 0.03$), and −0.26 ± 0.49 D ($p = 0.02$), respectively. As accommodative relaxation continued, the RPRE values recorded at 15 min postnearwork were no longer different from baseline RPRE (mean difference, 0.055 ± 0.77 D; $p = 0.74$), and the concluding 45- and 60-min postnearwork RPRE measurements resembled the baseline eye shape as well (mean difference, 0.0069 ± 0.48 D; $p = 0.95$ at the 45-min measurement; mean difference, 0.0036 ± 0.52 D; $p = 0.97$ at the 60-min measurement). Fig. 2 illustrates these changes.

Attempts were made to investigate whether other factors may have been related to the more prolate eye shape that was induced at the onset of accommodation. Subjects' refractive error was compared to their RPRE-measured eye shape because the two variables have been previously shown to be correlated.[4] In addition, each subject's initial accommodative response was evaluated against their refractive error because it has been shown that myopes demonstrate a deficient accommodative response.[20] Subjects' refractive error was not correlated with their eye shape measured at baseline ($r = -0.20$; $p = 0.37$) and was also unrelated to their respective accommodative responses at the onset of accommodation ($r = 0.25$; $p = 0.26$). No correlation was found between each subject's refractive error and their measured RPRE-measured eye shape change at the onset of their accommodation ($r = 0.30$; $p = 0.17$). In addition, the subjects' accommodative response showed no correlation with their RPRE eye shape change at the onset of accommodation ($r = 0.26$; $p = 0.23$) and no correlation with their eye shape measured at baseline ($r = -0.18$; $p = 0.42$). This may be explained by the homogenous collection of myopic refractive errors among study participants. In addition, subjects' accommodative responses were narrowly distributed, limiting their variability and therefore making it more difficult to identify potential correlations.

The mean transient myopia observed among subjects immediately after cessation of the nearwork task was −0.30 ± 0.31 D ($p = 0.0002$), an amount consistent with previous studies using similar accommodative stimulus levels.[21–23] In the present study, transient myopia was measured as the change in equivalent sphere refractive error from baseline to postnearwork. It was significant only after immediate cessation of accommodation, and it had resolved by the 1-min postnearwork measurement (0.07 ± 0.32 D; $p = 0.31$). Attempts were made to uncover any potential relationship between each subject's transient myopia and changes in their RPRE eye shape over time. Interestingly, this analysis revealed that the subjects' transient myopia was negatively correlated with their RPRE-measured shape change between baseline and the cessation of accommodation ($r = -0.52$; $p = 0.01$) (Fig. 3). This correlation indicates that greater amounts of transient myopia were associated with eyes that had changed the least toward an oblate shape. Transient myopia and changes in RPRE at other times failed to show significant correlations. Additionally, the RPRE change between immediate cessation of accommodation and 1 min postnearwork was not correlated with the disappearance of subjects' transient myopia that occurred during the same time interval ($r = -0.13$; $p = 0.57$).

DISCUSSION

Repeatability

The mean difference and 95% limits of agreement between occasions of primary-gaze noncycloplegic autorefraction that was recorded in the present study (0.01; −0.50 to +0.52 D) closely resembles the repeatability values found in previous studies (−0.007; −0.72 to +0.71 D[24] and 0.03; −0.52 to +0.58 D).[25]

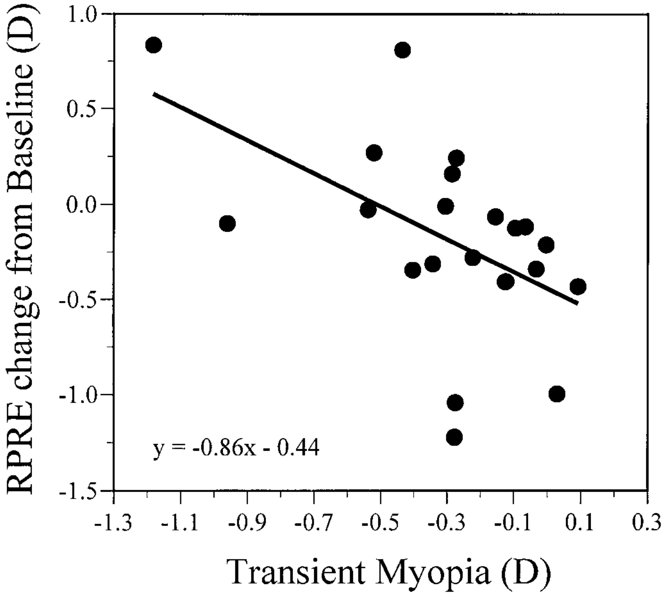

FIGURE 3.

Correlation between the subjects' transient myopia and their RPRE change between baseline and relaxation of accommodative (0 D, 0-min recovery).

In addition, the mean difference and 95% limits of agreement between occasions of RPRE measurements that were recorded in the present study (−0.05; −0.73 to +0.63 D) demonstrate a similar level of repeatability to primary-gaze autorefraction values. Consequently, the Canon R-1 seems to have an acceptable degree of repeatability in its measurement of primary-gaze and peripheral-gaze autorefraction and relative peripheral refractive error. Future studies considering use of the R-1 or other autorefractors to determine RPRE may be guided by this information with respect to sample size planning.

Accommodation and RPRE

The variation of ocular shape during and then after accommodation suggests that multiple factors, acting either simultaneously or successively, may have been responsible for the observed results. The finding that eye shape first became more prolate when accommodation was initiated is consistent with the model that increased choroidal tension during accommodation would result in a more prolate contour. As accommodation was maintained, the more prolate ocular shape gradually regressed and returned to the original baseline shape by the completion of the second hour of accommodation. Decreasing accommodative responses from subject fatigue during the course of the nearwork task would potentially account for this decay of the more prolate eye shape. However, analysis of the subjects' accommodative responses during the nearwork task revealed that the subjects had sustained their initial accommodative response throughout the near task. This result indicates that accommodative response variation over time was not responsible for the decay of eye shape toward a less prolate shape observed during the accommodative nearwork task.

Consequently, the decay of the initially more prolate-shaped eyes during sustained accommodation was not consistent with the previously discussed equatorial restriction model, nor is it consistent with sustained nearwork being a direct cause of ocular distortion associated with myopia. It was predicted that a prolonged action of accommodation would produce a sustained tension within the choroid and therefore a sustained change in shape. Nevertheless, the resultant decay of the initially more prolate eye shape that occurred when choroidal tension was sustained suggests that the choroid tissue of the eye's vascular tunic may possess slow compensatory recoil or nonelastic properties. If choroidal tension induced a more prolate shape, then a choroidal hysteresis may be an explanation for the observed decay away from the induced prolate shape seen in the final nearwork RPRE measure. Furthermore, this reduction in tension from choroidal hysteresis may explain the behavior of RPRE after relaxation of accommodation. The RPRE-measured ocular shape became significantly less prolate than baseline once accommodation was relaxed, and this contour remained present for nearly 30 min after the onset of accommodative relaxation. A more flaccid choroid than was present at baseline may result in a less prolate, more spherically shaped eye than observed at baseline. The fact that a less prolate eye shape was seen for up to 30 min after the accommodation had been relaxed suggests that the choroid's physical features perhaps remained relatively loose and flaccid after accommodation had ceased. There seems to be some variability of the RPRE-measured eye shape at the 15-min postnearwork measure, which may represent a time when the underlying hysteresis may have been breaking down and a natural choroidal tension was restoring the previously flaccid choroid to near-baseline values. In conclusion, the variation of eye shapes observed over time may be the result of unique physical features of the choroid that were susceptible to the stretching and relaxing forces induced by accommodation.

Recognizing that the choroid was presumably more flaccid at the time accommodation was first relaxed and that transient myopia was also evident at this time, it was hypothesized that the two events were potentially related to one another. One possibility is that a flaccid choroid would allow ciliary processes and zonules to release their resting tension on the crystalline lens and consequently the lens would assume a slightly more accommodated shape. Such a mechanism would explain the presence of nearwork-induced transient myopia among the subjects at the conclusion of their nearwork activities. However, an analysis of subjects' transient myopia and their RPRE-measured shape change from baseline to immediate cessation of accommodation resulted in the two factors being negatively, rather than positively, correlated. This finding implies that eyes that had most changed toward a more oblate shape were associated with the least amounts of transient myopia. As a result, choroidal relaxation does not seem to place the eye in a transient myopic state. Axial length changes are also an unlikely explanation for transient myopia. Increases in axial length with accommodation have previously been reported as minimal, on the order of 5.2 μm in myopic subjects corresponding to a dioptric change of approximately -0.014 D.[13] Because of these findings, it seems reasonable to suggest that nearwork-induced transient myopia is the result of lingering of ciliary muscle tension from the accommodative effort that preceded it. Perhaps the lack of hysteresis during sustained accommodation not only helped to maintain a prolate shape after relaxation, it also required more ciliary effort during sustained accommodation and contributed to the transient myopia.

One potential limitation of this study is that only one point was measured in the periphery of the subjects' eyes. However, making inferences about ocular shape using only one point seems to be justified based on the results of two previous studies in which multiple points at various field angles were measured.[3, 17] Both studies found a high degree of symmetry between the two hemifields for most eyes. Specifically, Rempt et al.[3] found that only 14 of 442 subjects had marked difference between their nasal and temporal peripheral refractions. Millodot[17] reported asymmetry in the peripheral refraction measurements, however the difference was only significant for field angles of less than 30°. Citing these earlier studies, Mutti et al.[4] recently performed refractions at a point 30° in the periphery to relate ocular shape and refractive error in children. This methodology resulted in significant correlations between subjects' refractive error and their eye shapes measured with single-point peripheral refraction.

The RPRE-measured ocular shape changes with accommodation could have been the result of aberrations present in the subjects' eyes. Earlier studies have determined that as the degree of myopia increases (according to axial length and equivalent sphere measures), the peripheral cornea has a tendency to steepen or be less prolate in shape.[26, 27] Applegate et al.[28] have suggested that myopic eyes are associated with more positive spherical aberration than hyperopic or emmetropic eyes. All subjects in the present study were myopic to some degree. However, despite the possibility of higher amounts of aberrations, all of the subjects in the present study were used as their own controls for any changes that may have occurred. Consequently, each subject's ocular aberrations would be included in their baseline and time-course RPRE measures throughout the protocol. For this reason, it seems unlikely that ocular aberrations interfered with ocular shape change measurements.

The change in eye position from primary gaze to peripheral gaze was also considered as a possible contributor to induction of the more prolate eye shape seen at the onset of accommodation. Rotation of the globe provided the potential for increased tension on the globe from the extraocular muscles when the eye assumed its 30° peripheral-gaze position. However, this is likely not responsible for the measured shape change because the nonaccommodated baseline RPRE and 3 D accommodative nearwork RPRE measurements were performed at identical primary-gaze and 30° peripheral-gaze directions. Nevertheless, if the measured eye did, in fact, respond to tension from the surrounding extraocular musculature in extreme peripheral gaze, the peripheral refraction would be expected to become more myopic, which is indicative of a more *oblate* shaped eye.[2] We observed the opposite, namely a more prolate shape during accommodation and a less prolate shape during relaxation. To eliminate the possibility that extraocular muscle tension from accommodative convergence may be responsible for the induced prolate shape with accommodation, future studies could elicit accommodation using pilocarpine.

One of the most interesting outcomes of this study was the suggestion that the choroid of adult eyes exhibits hysteresis properties when subjected to tension. This property seems to be at odds with a previous suggestion that prolonged equatorial restriction may contribute to a prolate eye.[4] Perhaps hysteresis is limited to adult eyes. It is possible that younger subjects or perhaps emerging myopes possess significantly different choroidal properties; specifically, their choroid may hover at a "hysteresis limit" in which they have no reserve absorption of choroidal tension. If this were the case, these younger eyes might exhibit a sustained change toward a more prolate shape with prolonged accommodation or equatorial restriction rather than a decay of this shape toward its resting position, as seen in the present study. For this reason, future studies investigating the effects of accommodation on ocular shape should consider the inclusion of newly myopic children in the sample.

In future studies, other methods may be used for the measurement of eye shape changes with accommodation including A-scan ultrasonography and magnetic resonance imaging (MRI). Such methods would not be affected by potential errors from optical factors influencing peripheral refraction. For example, optical models suggest that accommodation may affect peripheral and central refraction differently, potentially shifting RPRE results up or down during nearwork.[19] The changes seen within a particular accommodative level, however, would be unaffected by such errors. The relatively common use of A-scan in clinical research would certainly enable the method to be easily understood and performed, however its repeatability is substantially limited relative to other instruments.[24] Measurement of ocular shape may be performed more directly by MRI scanning devices as their resolution capabilities continue to expand in the presence of computing and imaging technology advancements. In fact, Strenk et al.[29] have recently used high-resolution MRI images of the eye to measure the relationship between ciliary muscle contraction and crystalline lens. Repeatability of the dimensional data extracted from the MRI images was accurate to within the image resolution of the MRI device (0.156 mm, or approximately 0.40 D). Consequently, MRI instrumentation seems to be a feasible method to provide precise measurements of the dynamic functions of the eye in future studies.

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REFERENCES

1. Deller J, O'Connor A, Sorsby A. X-ray measurement of the diameters of the living eye. Proc R Soc Lond (Biol) 1947;134:456–7.
2. Ferree C, Rand G, Hardy C. Refraction for the peripheral field of vision. Arch Ophthalmol 1931;5:717–31.
3. Rempt F, Hoogerheide J, Hoogenboom WP. Peripheral retinoscopy and the skiagram. Ophthalmologica 1971;162:1–10.
4. Mutti DO, Sholtz RI, Friedman NE, Zadnik K. Peripheral refraction and ocular shape in children. Invest Ophthalmol Vis Sci 2000;41: 1022–30.
5. Angle J, Wissmann DA. Age, reading, and myopia. Am J Optom Physiol Opt 1978;55:302–8.
6. Young FA, Leary GA, Baldwin WR, West DC, Box RA, Harris E, Johnson C. The transmission of refractive errors within Eskimo families. Am J Optom Arch Am Acad Optom 1969;46:676–85.
7. Rosner M, Belkin M. Intelligence, education, and myopia in males. Arch Ophthalmol 1987;105:1508–11.
8. McBrien NA, Adams DW. A longitudinal investigation of adult-onset and adult-progression of myopia in an occupational group: refractive and biometric findings. Invest Ophthalmol Vis Sci 1997; 38:321–33.
9. Zylbermann R, Landau D, Berson D. The influence of study habits on myopia in Jewish teenagers. J Pediatr Ophthalmol Strabismus 1993;30:319–22.
10. Mutti DO, Zadnik K, Fusaro RE, Friedman NE, Sholtz RI, Adams AJ. Optical and structural development of the crystalline lens in childhood. Invest Ophthalmol Vis Sci 1998;39:120–33.
11. Zadnik K. The Glenn A. Fry Award Lecture: myopia development in childhood. Optom Vis Sci 1995;1997;74:603–8.
12. Tamm E, Lutjen-Drecoll E, Jungkunz W, Rohen JW. Posterior attachment of ciliary muscle in young, accommodating old, presbyopic monkeys. Invest Ophthalmol Vis Sci 1991;32:1678–92.
13. Drexler W, Findl O, Schmetterer L, Hitzenberger CK, Fercher AF. Eye elongation during accommodation in humans: differences between emmetropes and myopes. Invest Ophthalmol Vis Sci 1998;39: 2140–7.
14. Moses R. Adler's Physiology of the Eye, 5th ed. St Louis: CV Mosby, 1970:359.
15. van Alphen G. On emmetropia and ametropia. Ophthalmol Suppl 1961;142:1–92.
16. Lele P, Grimes P. The role of neural mechanisms in the regulation of intraocular pressure in the cat. Exp Neurol 1960;2:199–220.
17. Millodot M. Effect of ametropia on peripheral refraction. Am J Optom Physiol Opt 1981;58:691–5.
18. Love J, Gilmartin B, Dunne MCM. Relative peripheral refractive error in adult myopia and emmetropia. Invest Ophthalmol Vis Sci 2000;41:S302.
19. Dunne MC. A computing scheme for determination of retinal contour from peripheral refraction, keratometry and A-scan ultrasonography. Ophthalmic Physiol Opt 1995;15:133–43.
20. Gwiazda J, Thorn F, Bauer J, Held R. Myopic children show insufficient accommodative response to blur. Invest Ophthalmol Vis Sci 1993;34:690–4.
21. Blustein GH, Rosenfield M, Ciuffreda KJ. Does dark accommodation really change following sustained near fixation? Optom Vis Sci 1993;70(Suppl):16.
22. Ehrlich DL. Near vision stress: vergence adaptation and accommodative fatigue. Ophthalmic Physiol Opt 1987;7:353–7.
23. Ong E, Ciuffreda KJ, Rosenfield M. Effect of target proximity on transient myopia induced by equidioptric stimuli. Optom Vis Sci 1995;72:502–5.
24. Zadnik K, Mutti DO, Adams AJ. The repeatability of measurement of the ocular components. Invest Ophthalmol Vis Sci 1992;33: 2325–33.
25. Watson R, Irvin BC, Zadnik K. The repeatability of autorefractors. Optom Vis Sci 1999;76(Suppl):185.
26. Carney LG, Mainstone JC, Henderson BA. Corneal topography and myopia: a cross-sectional study. Invest Ophthalmol Vis Sci 1997;38: 311–20.
27. Horner DG, Soni PS, Vyas N, Himebaugh NL. Longitudinal changes in corneal asphericity in myopia. Optom Vis Sci 2000;77: 198–203.
28. Applegate RA, Howland HC, Buettner J, Cottinghan AJ, Sharp R, Yee R. Corneal aberrations before and after radial keratometry (RK) calculated from videokeratometric measurements. In: Vision Science and Its Applications, Vol 2. OSA Technical Digest Series. Washington, DC: Optical Society of America, 1994:58–61.
29. Strenk SA, Semmlow JL, Strenk LM, Munoz P, Gronlund-Jacob J, DeMarco JK. Age-related changes in human ciliary muscle and lens: a magnetic resonance imaging study. Invest Ophthalmol Vis Sci 1999;40:1162–9.

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