Accommodative Lag before and after the Onset of Myopia

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PURPOSE. To evaluate accommodative lag before, during the year of, and after the onset of myopia in children who became myopic, compared with emmetropes.

METHODS. The subjects were 568 children who became myopic (at least −0.75 D in each meridian) and 539 children who were emmetropic (between −0.25 D and +1.00 D in each meridian at all visits) participating between 1995 and 2003 in the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) Study. Accommodative lag was measured annually with either a Canon R-1 (Canon USA, Lake Success, NY; no longer manufactured) or a Grand Seiko WR 5100-K (Grand Seiko Co., Hiroshima, Japan) autorefractor. Subjects wore their habitual refractive corrections while viewing a letter target accommodative stimulus of 4 D (either in a Badal system or at 25 cm from the subject, designated Badal and near, respectively) or of 2 D (Badal only). Refractive error was measured with the same autorefractor in subjects under cycloplegia. Accommodative lag in children who became myopic was compared to age-, gender-, and ethnicity-matched model estimates of emmetropic values for each annual visit from 5 years before, through 5 years after, the onset of myopia.

RESULTS. In the sample as a whole, accommodative lag was not significantly different in children who became myopic compared with model estimates in emmetropes in any year before onset of myopia for either the 4-D or 2-D Badal stimulus. For the 4-D near target, there was only a greater amount of accommodative lag in children who became myopic compared with emmetropes 4 years before onset (difference, 0.22 D; P = 0.0002). Accommodative lag was not significantly elevated during the year of onset of myopia in any of the three measurement conditions (P < 0.82 for all three). A consistently higher lag was seen in children after the onset of their myopia (range, 0.13–0.56 D; P < 0.004 for all comparisons). These patterns were generally followed by each ethnic group, with Asian children typically showing the most, African-American and white children showing the least, and Hispanic children having intermediate accommodative lag.

CONCLUSIONS. Substantive and consistent elevations in accommodative lag relative to model estimates of lag in emmetropes did not occur in children who became myopic before the onset of myopia or during the year of onset. Increased accommodative lag occurred in children after the onset of myopia. Elevated accommodative lag is unlikely to be a useful predictive factor for the onset of myopia. Increased hyperopic defocus from accommodative lag may be a consequence rather than a cause of myopia. (Invest Ophthalmol Vis Sci. 2006;47:837–846) DOI:10.1167/iovs.05-0888

The blur hypothesis has been a critically important theory in the field of refractive error. Wallman et al. demonstrated that the chick could be made highly myopic in response to modest environmental manipulation. Ten years later, Schaeffel et al. showed that growth of the chick eye could be tuned to the sign and power of lenses simulating refractive errors. Since that time, numerous experiments using the lens paradigm have advanced the theory that growth of the eye is guided toward emmetropia by visual feedback, sensing the sign and magnitude of blur. Hyperopic defocus, where the conjugate point of the object of regard is behind the retina, is a putative stimulant to eye growth that moves the retina toward the conjugate point. Myopic defocus is reported to inhibit axial elongation, more robustly in the chick eye than in the mammalian eye, with the choroid of the chick pushing the retina forward toward the myopic focal point. This pattern of response occurs in numerous animal species including the monkey, mammose,6 tree shrew (Sigmavart JT, et al. JOVS 1993;34:ARVO 1208), guinea pig,7 and chick.8 The finding that myopic subjects age 5 to 18 years accommodate less accurately than emmetropic subjects suggests that a link exists between hyperopic defocus and accelerated axial growth in both the animal-based lens paradigm and human myopia.9,10

Given that existing myopia is associated with a deficient accommodative response and that hyperopic defocus may be a stimulant to axial growth, the question arises of whether increased accommodative lag is a risk factor for myopia. Does increased accommodative lag precede the onset of myopia? Three studies in humans suggest that increases in accommodative lag occur before the onset of myopia. In the present study, we analyzed accommodative lag before onset, during the year of onset, and after the onset of myopia in comparison to accommodative lag in emmetropic children over an extended period in a large sample of ethnically diverse children.

METHODS

Subjects were children participating between 1995 and 2003 in the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error
The prevalence of myopia varies by ethnic group, with children of Asian descent typically having the highest prevalence, regardless of whether they live in Asia or the United States. Differences in accommodative lag as a function of ethnicity, particularly before the onset of myopia, may explain some of this variation in prevalence.

Ethnic group designation was determined by parental report on a medical history form. Parents selected one of the following six ethnic designations (corresponding to the categories used by the National Institutes of Health): American Indian or Alaskan Native; Asian or Pacific Islander; black, not of Hispanic origin; Hispanic; white, not of Hispanic origin; and other, or unknown. Ethnicity was assigned to the target ethnic group for the given site when parents provided more than one ethnic designation that included the site’s targeted ethnicity (2% of subjects). If parents provided more than one ethnic designation and neither included the site’s targeted designation, ethnicity was assigned to the nonwhite ethnicity of the two. Any missing parent-reported ethnicity was filled in from investigator observation (2% of subjects). This method shows excellent agreement with parent-reported ethnicity. The sample for this report was 50% female with the following representation with respect to ethnicity: 16.7% Native American, 18.8% African-American, 17.3% Asian-American, 19.1% white, and 28.1% Hispanic. Children ranged in age from 6 to 15 years (first through eighth grade). Emmetropes were defined as children with refractive error between 0.25 D and 1.00 D (exclusive) in each meridian at all study visits by cycloplegic autorefraction (n = 705). Myopia was defined as at least 0.75 D in each principal meridian during at least one study visit (n = 999). Children who did not fall into either of these two categories (i.e., children who were neither myopic nor emmetropic but were hyperopic, had simple hyperopic or myopic astigmatism, or were mixed astigmats on at least one visit) were not analyzed (n = 3226). Although the number excluded was large, the inclusion criteria were strict, so that clearer contrasts might be drawn between two distinct and unambiguous groups. For a child to be included in the “became myopic” group, he or she must have had at least one nonmyopic examination. Children with at least 0.75 D of myopia in each principal meridian with no previous nonmyopic visits (i.e., prevalent myopes who had no identifiable onset visit) were excluded from the analysis (n = 370). Additional reasons for exclusion among myopes were that ethnicity was not recorded (n = 10) or that visits occurred between 1989 and 1994, before the inclusion of lag measurement in the CLEERE protocol (n = 51). Two emmetropic children also had no ethnicity data or had visits that occurred between 1989 and 1994 (n = 164), leaving 568 children who became myopic and 539 children who were emmetropes at all visits for analysis. The number of “became myopic” children at each study visit is given in Table 1.

Trained and certified examiners measured refractive error and accommodative response with the Canon R-1 autorefractor (Canon USA, Lake Success, NY; no longer manufactured) between 1989 and 2000 and with the Grand Seiko WR 5100-K (Grand Seiko Co., Hiroshima, Japan) autorefractor at all sites from 2001 to 2003. Accommodative response was measured before cycloplegic measurement of refractive error. Accommodative response was measured in the right eye during assessment of the accommodative convergence-accommodation (AC/A) ratio by using methods described in detail previously. The accommodative stimulus was a 4 × 4 grid of letters viewed monocularly, with each letter and space between letters subtending 38.75 minutes of arc at the eye (20/155 equivalent). The target was illuminated by ambient room lighting supplemented by accessory lights to produce a target luminance between 30 and 50 cd/m².

Accommodative stimulus levels of 2.0 and 4.0 D relative to optical infinity were produced by moving the letter target on a track behind a +6.50 D Badal lens. The dioptric stimulus provided by each track was calibrated with a 6 × telescope and trial lenses. The nominal 2.0-D stimulus ranged across clinics between 2.0 and 2.25 D and the nominal 4.0-D stimulus ranged between 4.0 and 4.37 D. The actual stimulus level at each clinic was accounted for in the calculation of the amount of lag. Because accommodative lag may be less in myopes when the blur is caused by target distance rather than lenses, an assessment was made of the monocular accommodative response to a 4.0-D stimulus consisting of a 4 × 4 grid of letters with the same angular subtense as in the Badal system placed 25 cm from the subject (designated “near,” as opposed to “Badal”). The accommodative lag from the 4.0-D Badal target was considered the primary outcome, because the greater lag in response to optical blur was considered the most likely to show differences compared with that in emmetropes. The 4.0-D target represented a more natural, real-world accommodative stimulus. The 2.0-D Badal target assessed lag at a second, intermediate stimulus level within the range of possible working distances for children.

At least five autorefractor readings were taken of the right eye in primary gaze. In grades one and two (age, 6–7 years), a minimum of three readings was acceptable because of younger children’s shorter attention spans. Ametropia was corrected only if the subject wore a spectacle or contact lens correction to the testing session. Measurements therefore were of the habitual accommodative state, as determined by the child’s own compliance with the wearing of a refractive correction. Contact lens wearers left their own lenses in place. For spectacle wearers, subjective refraction techniques were simulated by moving the letter target along the Badal track away from the subject’s right eye, to relax accommodation as if plus lenses were being added. Readings were taken at the point where the target was clear, and any movement to further relax accommodation resulted in the subject’s reporting blur. The sphere and, if necessary, the cylindrical trial lens correction were placed in a trial clip over the right eye of the glasses frames. The trial lens correction was modified as needed to keep the overrefraction at the 0.0-D stimulus level within ±0.50 D for sphere and ±1.00 D or less for cylinder. All stimulus levels and raw autorefractor accommodative responses among spectacle wearers were adjusted for lens effectivity into corrected values. For cycloplegic autorefraction, subjects fixated a reduced Snellen target through a +4.00-D Badal lens in primary gaze. When subjects had an iris color of grade 1 or 2,19 testing was performed 30 minutes after 1 drop of proparacaine 0.5% and 2 drops of tropicamide 1%. When subjects had an iris color darker than grade 2, testing was performed 30 minutes after 1 drop of proparacaine 0.5% and 1 drop each of tropicamide 1% and tropicamide 1%

Table 1. Number of Became Myopic Subjects at Each Study Visit

<table>
<thead>
<tr>
<th>Visit</th>
<th>n</th>
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<tr>
<td></td>
<td>5</td>
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<tr>
<td>26</td>
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<tr>
<td>541</td>
<td>362</td>
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and cyclopentolate 1%.20 Ten autorefractor measurements were made according to a standard protocol for cycloplegic autorefraction.21

**Emmetrope Model**

Separate growth curves were constructed for emmetropes for accommodative lag for each target type (Badal and near targets at the 4-D level and Badal at the 2-D level) as a function of age. The best-fitting models as defined by the Akaike Information Criterion were those that incorporated the natural log of age plus the natural log of age squared for all three dependent measures.22 These methods have been described in detail previously for modeling of emmetropic component development.23 Gender and ethnicity and the interaction between ethnicity and age were subsequently included in the models. The regression coefficients for ln(age) and ln(age)² for each target type, gender, and ethnic group were derived on computer by mixed ANOVA modeling with repeated measures (SAS, ver. 9.1; SAS Institute, Cary, NC).

**Became-Myopic Data**

To be included in the became-myopic group, a subject had to be nonmyopic on at least one visit before a myopic visit. The year the became-myopic subject first met the myopia criterion was defined as year 0, the year of onset. The first study year before onset was −1, 2 years prior was −2, and so forth out to −5 years before onset. The number of children in years 0 and −1 in Table 1 are not the same, because some children missed visits between their last nonmyopic visit and their onset visit. Each study year after onset in a given subject was designated as +1, +2, and so forth out to +5. The age of each became-myopic subject at each study visit was applied to the appropriate emmetrope regression equation. This provided an age, gender, and ethnicity-matched emmetropic value of lag for every became-myopic data point. Mixed modeling was then used to compare the mean difference between became-myopic data and the emmetrope model values as a function of study visit for each target type. A significance level of $P < 0.01$ is used in consideration of the large sample size. This level of adjustment is somewhat arbitrary, but represents a compromise between filtering out spurious findings while allowing small differences on the order of 0.10 to 0.20 D to reach significance. Throughout the rest of the text, became-myopic will refer to the data from children in that category and emmetrope will refer to the values estimated from the model derived from emmetropic children’s data.

**Results**

**4-D Badal**

The amount of lag to the 4-D Badal stimulus in became-myopic children and in emmetropes as a function of years relative to the onset of myopia is shown in Figure 1A. Emmetropes generally showed a consistent amount of lag, on the order of 0.8 to 0.9 D, throughout the observation period from year −5 through year +5. Before onset, the became-myopic group had a similar amount of lag compared with emmetropes (Fig. 1B). There were no significant differences between emmetropes and became-myopic children in years −5 through −1 with the exception of year −3 (less lag in became-myopic children, difference, −0.14 D; $P = 0.0015$). There was no significant difference (0.007 D; $P = 0.82$) between became-myopic children and emmetropes during the year of onset. Consistently higher levels of lag were seen in became-myopic children compared with emmetropes in each of the postonset years +1 through +5. This difference reached 0.56 D by year +5 ($P < 0.0001$ for years +1 through +5).

**4-D Near Target**

The amount of lag for the 4-D near target in became-myopic children and emmetropes as a function of years relative to the onset of myopia is shown in Figure 2A. Emmetropes had a consistent amount of lag, on the order of 1.00 D, throughout the observation period from year −5 through year +5. Before onset, the became-myopic group had more lag than the emmetropes only in year −4 (difference, 0.22 D; $P = 0.0002$; Fig. 2B). There was no significant difference between emmetropes and became-myopic children in the year of onset (difference, −0.009 D; $P = 0.74$). Differences between emmetropes and became-myopic children occurred after onset, in years +1 through +3, with became-myopic children showing greater lag than the emmetropes. The difference between groups with the 4-D near target was smaller than with the 4-D Badal target, only reaching 0.15 D by year +3 ($P < 0.004$ for years +1 through +3).

**2-D Badal**

The amount of lag in accommodation to the 2-D Badal stimulus in became-myopic children and emmetropes as a function of years relative to the onset of myopia is shown in Figure 3A. Emmetropes again showed a consistent amount of lag (on the order of 0.7 D), throughout the observation period from year −5 through year +5. There were no significant differences
between emmetropes and became-myopic children in years -5 and -4 (Fig. 3B). The became-myopic group had less lag compared with emmetropes in preonset years -3 and -1 (difference, -0.11 D; \( P = 0.003 \)) and -0.20 D; \( P < 0.0001 \), respectively), in the year of onset (difference, -0.29 D; \( P < 0.0001 \)), and in year +1 after onset (difference, -0.11 D; \( P = 0.003 \)). Consistent elevations in lag were not recorded in became-myopic children compared with emmetropes until years +3 through +5 (differences, 0.38–0.62 D; \( P < 0.004 \) for each comparison). Hispanic became-myopic children showed elevated lag with the 4-D Badal stimulus in years +1 through +5 (differences, 0.28–0.76 D; \( P < 0.0001 \) for each comparison). Lag was significantly lower in became-myopic children than in emmetropes with the 2-D Badal stimulus in several ethnic groups (Fig. 5). This lag was noted near onset in all groups: Asians in year 0, Hispanics in years -3 through +1; whites in year -1 through +2; and African-Americans in years -3, -1,

Ethnicity

Each ethnic group tended to follow the pattern described for the sample as a whole (Figs. 4A–C). In general, relative to emmetropes, Asian became-myopic children tended to have the highest, African-American or white children the lowest, and Hispanic children intermediate values of lag compared with corresponding emmetropes values. Accommodative lag was elevated before the onset of myopia with all three targets only in white became-myopic children and only in year -4 (Fig. 5; difference, 0.39 D with 4-D Badal, 0.41 D with 2-D Badal; and 0.36 D with 4-D near, \( P < 0.0083 \) for each comparison). Lag was either elevated sporadically in other ethnic groups in other preonset years (higher for one of the 4D stimulus conditions but not the other, or not sustained over time) or was significantly lower compared with emmetropes (Fig. 5). At onset, only Asian became-myopic children had elevated lag with the two 4-D targets (difference: 0.16 D with 4-D Badal, 0.15 D with 4-D near, \( P < 0.009 \); Fig. 5). Asian became-myopic children showed elevated lag compared with emmetropes in both 4-D stimulus conditions in years +1 through +4 (differences: 0.38–0.62 D; \( P < 0.004 \) for each comparison). Hispanic became-myopic children showed elevated lag with the 4-D Badal stimulus in years +1 through +5 (differences, 0.28–0.76 D; \( P < 0.0001 \) for each comparison). Lag was significantly lower in became-myopic children than in emmetropes with the 2-D Badal stimulus in several ethnic groups (Fig. 5). This lag was noted near onset in all groups: Asians in year 0, Hispanics in years -3 through +1; whites in year -1 through +2; and African-Americans in years -3, -1,
and 0. Consistent elevations in lag with the 4-D stimulus occurred after the onset of myopia in Asian became-myopic children in years +2 through +4 (differences, 0.32–0.49 D; $P < 0.0001$ for each comparison).

The effect of wearing a refractive correction on accommodative lag measurements was examined in became-myopic children. The percentage of children wearing a correction at each year relative to onset is given in Table 2. Only the interval from years $-2$ to $+2$ was considered, as virtually all children had their refraction either uncorrected before this time or corrected after it. As expected, this percentage varied by study visit relative to the onset of myopia. Approximately 10% of children obtained and wore a correction before they met the $-0.75$-D criterion for myopia, and approximately 30% did not wear a correction 2 years after the onset of clinically significant myopia. As might be expected, became-myopic children wearing a refractive correction had more myopia by spherical equivalent at each visit than did those who were not wearing a refractive correction. Accommodative lag was not significantly elevated in became-myopic children with corrected or uncorrected refractive error compared with emmetropes before onset in the three stimulus conditions (Fig. 6). Lag was greater in became-myopic children with correction than in emmetropes in all three stimulus conditions at onset (differences: 0.15 D with 4-D Badal, 0.23 D with 4-D near, 0.12 D with 2-D Badal; $P < 0.0001$ for each comparison) and each year after onset (differences: 0.23–0.46 D; $P < 0.0001$ for each comparison). Became-myopic children who did not wear a refractive correction had smaller amounts of lag compared with emmetropes at onset in two of the stimulus conditions (differences: $-0.12$ D with 4-D near and $-0.49$ D with 2-D Badal; $P < 0.0001$ for each comparison). Became-myopic children with uncorrected refractive error also had smaller amounts of lag after onset in response to the 2-D Badal stimulus (differences = $-0.55$ to $-0.69$ D; $P < 0.0001$ for each comparison).

All clinics changed to the Grand Seiko autorefractor in 2001. We assessed the impact of this change in several ways. Children measured at years $-1$, 0, and +1 with the Canon R-1 before 2001 compared with those measured with the Grand Seiko after 2001 showed an offset between instruments of 0.2 D. This is less than the eventual difference of nearly 0.6 D between became-myopic children and emmetropes in the 2-D and 4-D results. In addition, the differences between became-myopic children and emmetropes shown in Figures 1B, 2B, and 3B do not parallel each other, as might occur with instrument bias. These differences are nearly flat across visits with the 4-D near target but rise abruptly at visit +1 with the 4-D and 2-D Badal targets. In addition, instrument bias should affect emmetrope data as well, yet these results are nearly flat in all three stimulus conditions (Figs. 1A, 2A, 3A). The robustness of results in the critical interval between $-1$ and +1 was also evaluated by adjustment of the entire data set for instrument, study site, and study year. This statistical procedure removes the offset between instruments across sites and study years. The average difference ($\pm SD$) across visits between the adjusted values and the unadjusted values was 0.01 $\pm 0.10$ D and never exceeded 0.10 D at any visit between $-1$ and +1 in each of the three stimulus conditions. The primary result of no change in lag or a decrease in lag before onset followed by an increase in lag after onset also occurred in these adjusted data. For example, lag changed little in became-myopic children compared with emmetropes between years $-1$ and 0 in both the adjusted and the unadjusted data sets for the 4-D Badal target (by $-0.04$ D and $-0.01$ D, respectively). Lag increased in became-myopic children compared with emmetropes between visits 0 and +1 in both the adjusted and the unadjusted data sets for the 4-D Badal target, by 0.16 and 0.25 D, respectively.

**DISCUSSION**

In visits before and including onset, there were no consistent or substantive differences between became-myopic and emmetropic children (4-D Badal and near targets) or lag was lower in became-myopic children (2-D Badal). Elevations in lag fol-
lowed onset by one or more years. This finding is consistent with reports of increased lag in prevalent cases of myopia in children.\textsuperscript{9,10} This pattern occurred across the ethnic groups with reports of increased lag in prevalent cases of myopia followed onset by one or more years. This finding is consistent with reports of increased lag in prevalent cases of myopia in children with the exception of Asian children in the year of onset. These findings do not suggest a substantial role for accommodative lag in the etiology of myopia. The only other became-myopic children who showed increased lag at onset wore a spectacle correction. Increased lag at onset in this small group may not be a very useful predictive factor, considering that the wearing of a correction already identifies a child as myopic. Children wearing a refractive correction may display more lag because they have a greater accommodative demand than those without corrected refraction; this “add” reached an average of 1.78 D by visit +2 (Table 2). Accommodative demand was likewise reduced, along with lag, for intermediate distance tasks in became-myopic children if their refraction was uncorrected, as seen in the 2-D Badal results. Uncorrected children may be exposed to less hyperopic defocus than emmetropes during the development of clinically significant myopia if they engage in tasks that include substantial time at intermediate distances.

Elevations in lag that follow but do not precede onset suggest that increased lag may be a consequence rather than a cause of myopia. CLEERE examinations are performed only annually, however, and it is not possible to know precisely at what point between visits that lag became elevated. Lag might be considered a causative factor if there were an elevation in lag at some unmeasured time, before onset but after year −1. The narrowness of this window of opportunity (i.e., less than 1 year), would certainly reduce the value of lag as a predictive factor or as the basis of any preventive intervention. Frequent measurements of refractive error would seem more useful for prediction of onset than frequent measures of lag. Lag would also have to be a very powerful factor to influence axial growth and refractive error in a short period. If this were the case, it might be expected that relieving excess lag, as with a plus addition at near, would have a more powerful effect than has been observed in recent bifocal or multifocal clinical trials.\textsuperscript{24–26} Even when the effects of multifocal lenses were analyzed in myopic children with greater than the median amount of accommodative lag, the rate of myopic progression over 3 years was reduced by only 21% relative to single-vision glasses wearers.\textsuperscript{27} It is also interesting to note that the average progression of myopia in COMET wearers of single-vision glasses was not significantly different between children with more than compared to less than the median amount of lag.\textsuperscript{27} These results argue against lag as having the power or influence needed to make a child myopic within 1 year.

Several processes may make increased lag a product rather than a cause of myopia. Simple disuse may occur, where uncorrected myopia decreases the need for accurate accommodation and therefore suppresses the accommodative response. Poor response from disuse should disappear, however, once myopic refraction is corrected. Elevations in lag were clearly present in became-myopic children for several years after onset, even when most of the myopic subjects wore a correction. Another possibility is that there is a sensory deficit in myopes that prevents them from fully appreciating the blur from their accommodative lag, essentially increasing their depth of field. This may happen at onset from the excessive retinal stretch that accompanies myopic axial elongation, resulting in decreased contrast sensitivity, reduced acuity, and decreased blur sensitivity. Although myopes have been reported to have poorer contrast sensitivity when acuity is reduced at higher levels of myopia,\textsuperscript{28,29} or when spherical aber-

### Table 2. Became Myopic Subjects Wearing a Refractive Correction or No Refractive Correction and Their Mean (±SD) Spherical Equivalent Refractive Error (SEQ)

<table>
<thead>
<tr>
<th>Visit</th>
<th>Corrected</th>
<th>Uncorrected</th>
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<tr>
<td></td>
<td>n (%)</td>
<td>SEQ (D)</td>
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<tr>
<td>−2</td>
<td>30 (7.9)</td>
<td>0.56 ± 0.40</td>
</tr>
<tr>
<td>−1</td>
<td>70 (13.9)</td>
<td>0.90 ± 0.45</td>
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<tr>
<td>0</td>
<td>198 (36.6)</td>
<td>1.58 ± 0.55</td>
</tr>
<tr>
<td>+1</td>
<td>207 (57.2)</td>
<td>2.09 ± 0.73</td>
</tr>
<tr>
<td>+2</td>
<td>177 (71.4)</td>
<td>2.52 ± 0.84</td>
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**FIGURE 5.** Significant differences (elevations or reductions) in accommodative lag between became-myopic children and emmetrope model data by visit and ethnic group. (A) 4-D Badal stimulus; (B) 4-D stimulus at 25 cm; and (C) 2-D Badal stimulus. Error bars, ± SEM. Missing bars indicate that differences were not significant between groups for that visit and ethnic group.
ration is substantial.\textsuperscript{50} Contrast sensitivity seems normal at lower levels of myopia or when acuity is normal.\textsuperscript{29,51,52} Magnification differences between spectacles and contact lenses can complicate these measurements. Strang et al.\textsuperscript{33} found that poorer acuity was correlated with the degree of myopia (even after adjustment for magnification effects) that most closely followed a pattern of posterior pole retinal stretching. If retinal stretching is present at the onset of myopia, then visual acuity might be affected. Perhaps a more direct test of the impact of possible sensory differences is provided by studies of blur sensitivity. In asking whether the depth of field is different in myopes compared with emmetropes, one study in children essentially found no differences between refractive groups using simulated target blur,\textsuperscript{34} whereas another in adults found a greater depth of field (0.08 D) in myopes using optical defocus in a bipartite Badal system.\textsuperscript{55} Therefore, even when seen, differences in blur sensitivity seem too small to account for the differences in accommodative lag that occur after myopia onset.

Higher-order optical aberrations may also affect the accommodative response. Degradation of the retinal image may reduce visual acuity and decrease accommodative accuracy, or aberrations may extend the depth of field in the form of a bifocal effect. In several large studies, advanced measurement techniques have been used to assess aberrations in refractive error. One found no correlation between second-order defocus and spherical aberration,\textsuperscript{36} whereas another found no correlation between refractive error and total root mean square (RMS) error, third-order, fourth-order, or spherical aberration.\textsuperscript{37} Of interest, the latter study argued that the lack of correlation was actually evidence for less spherical aberration in myopic eyes, as the aberrometry technique should induce spherical aberration as a function of myopic refractive error. This is consistent with the finding of less spherical aberration in low myopes compared with emmetropes (0.02-\textmu m difference) and no difference in total RMS.\textsuperscript{38} One study has reported more aberrations of fourth-order and higher in myopes than in emmetropes. In children, this difference was approximately 0.05 \textmu m of RMS error.\textsuperscript{39} As several investigators have noted, it appears difficult to make an argument that aberrations are of sufficient magnitude to have a substantial effect on refractive development.\textsuperscript{37,50}

Finally, blur adaptation is another factor related to accommodation and refractive error that merits discussion. Both myopes and emmetropes appear to undergo blur adaptation, but the adaptation has been shown to be greater in myopes, in the improvements they experience in grating acuity.\textsuperscript{41} Blur adaptation to a diffusing film has been reported to improve the accommodative response of myopes once the diffuser was removed and normal vision was restored, but had no effect on the response of emmetropes.\textsuperscript{42} If a greater amount of blur adaptation in myopes actually improves acuity and/or the accommodative response, it seems unlikely that blur adaptation could explain the elevated lag of accommodation that was recorded after the onset of myopia.

An alternate explanation for the elevated lag occurring after onset takes into account that prevalent myopes also have an increased AC/A ratio.\textsuperscript{18,43} Sensory differences in myopes might explain accommodative lag, but they do not explain the increase in convergence gain. The AC/A ratio should be constant despite increased lag, as it is reported to be linear across a wide range of levels of accommodative response.\textsuperscript{44} The basic tenet of this alternate view is that excessive ciliary and/or lenticular stretch in the enlarged myopic eye may produce increased equatorial tension,\textsuperscript{18} which may account for the structural and accommodative characteristics that are associated with myopia. Structurally, ciliary tension may also explain the prolate ocular shape that is found in myopia.\textsuperscript{45–50} With respect to accommodation, ciliary tension may increase the effort needed to accommodate, producing three characteristic features of accommodation termed pseudocycloplegia, because they mimic accommodative behavior in eyes under cycloplegia, which includes a decrease in open-loop accommodation,\textsuperscript{51} an increase in the AC/A ratio,\textsuperscript{52} and an increase in accommodative lag.\textsuperscript{7} If increased accommodative lag arises from the same equatorial restriction process, why would increased lag appear only after onset? Two factors may keep lag from showing any

**FIGURE 6.** Accommodative lag as a function of visit relative to the onset of myopia and correction status. (A) 4-D Badal stimulus; (B) 4-D stimulus at 25 cm; and (C) 2-D Badal stimulus. *Significant differences from zero. Error bars, ± SEM.
early differences. One is that accommodation is a closed-loop function. Assuming normal sensitivity, blur can become only so large before the accommodative response adjusts to keep the image within the depth of field. Myopes may need to expend more effort to accommodate, but they certainly have the amplitude available for the 4-D stimulus conditions in this study. Perhaps early equatorial restrictions do not place the kind of stress on the accommodative system that occurs after onset. Earlier differences in lag may also be suppressed by the presence of small negative spherical equivalent refractive errors before children meet the criterion for onset. The behavior of the AC/A ratio, not yet analyzed, may be a more sensitive open-loop measure of how accommodation is affected before, during, and after the onset of myopia.

Two previous studies and one recent investigation have reported that increased accommodative lag may precede the onset of myopia.\textsuperscript{11–13} Using binocular cross cylinder data from clinic records in four private practices as the estimate of accommodative lag, Goss\textsuperscript{11} found increased lag in emmetropic children who went on to become myopic compared with children who remained emmetropic, but only in one of four of the practices. When data were combined across practice locations, lag was not significantly higher before myopia onset.\textsuperscript{11} Drobe and St. Andre\textsuperscript{12} estimated lag by near retinoscopy in subjects less than 40 years of age who were classified on the basis of two refractions within 2 years either as stable emmetropes or premyopes. Unfortunately, approximately 0.24 D less hyperopia in the distance refractive error among the premetropes or premyopes. Unfortunately, approximately 0.24 D less hyperopia in the distance refractive error among the premyopes was included in the analysis, incorrectly increasing the lag for this group relative to stable emmetropes. At sample sizes of 18 to 25 subjects per group, it is not clear whether lag for this group relative to stable emmetropes. At sample sizes of 18 to 25 subjects per group, it is not clear whether lag for this group relative to stable emmetropes or premyopes. Unfortunately, approximately 0.24 D less hyperopia in the distance refractive error among the premyopes was included in the analysis, incorrectly increasing the lag for this group relative to stable emmetropes. At sample sizes of 18 to 25 subjects per group, it is not clear whether lag for this group relative to stable emmetropes or premyopes.

Perhaps early equatorial restrictions do not place the kind of stress on the accommodative system that occurs after onset. Earlier differences in lag may also be suppressed by the presence of small negative spherical equivalent refractive errors before children meet the criterion for onset. The behavior of the AC/A ratio, not yet analyzed, may be a more sensitive open-loop measure of how accommodation is affected before, during, and after the onset of myopia. References


**APPENDIX**

**The CLEERE Study Group (as of September 2005)**


**Department of Optibhalmology, University of Arizona, Tucson, Arizona:** J. Daniel Twelker, (Principal Investigator, 2000–present), Dawn Messer (Optometrist, 2000–present), Denise Flores (Study Coordinator, 2000–present), Rita Bhakta (Optometrist, 2000–2004).

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**Videophakometry Reading Center, The Ohio State University College of Optometry, Columbus, Ohio:** Donald O. Mutti (Director, 1997–present), Huan Sheng, (Reader, 2000–present), Holly Omlor (Reader, 2003–present), Melilha Rahmani (Reader, 2003–present).


Project Office, National Eye Institute, Rockville, Maryland: Donald F. Everett (Project Officer).

EXECUTIVE COMMITTEE: Karla Zadnik, (Chairman), Lisa A. Jones, Robert N. Kleinsteins, Ruth E. Manny, Donald O. Mutti, J. Daniel Twelker, Susan A. Cotter.

ERRATUM


There are two corrections to Figure 2A: (1) In Family 1, the mother (2468) is heterozygous for Val243fs and not Gly243fs; (2) In Family 2, one son (2633) is a carrier, so the box should be semifilled. The correct figure is shown below.

A: