Seasonal Variations in the Progression of Myopia in Children Enrolled in the Correction of Myopia Evaluation Trial

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Purpose. To investigate monthly and seasonal variations in the progression of myopia in children enrolled in the Correction of Myopia Evaluation Trial (COMET).

Methods. An ethnically diverse cohort of 469 myopic 6- to <12 year-old children was randomized to single vision or progressive addition lenses and followed for 3 years with 98.5% retention. Progression of myopia was measured semiannually by noncycloplegic autorefraction (Nidek ARK 700A) and annually by cycloplegic autorefraction, with the former measurements used in these analyses. The semiannual progression rate was calculated as (change in spherical equivalent refraction between two consecutive semiannual visits/number of days between the two visits) times 182.5. Months were categorized as the midpoint between two visit dates. Seasons were classified as winter (October through March) or summer (April through September). The seasonal difference was tested using a linear mixed model adjusting for demographic variables (age, sex, ethnicity), baseline refraction, and treatment group.

Results. Data from 358 children (mean [±SD] age = 9.84 ± 1.27 years; mean myopia = −2.54 ± 0.84 diopters [D]) met the criteria for these analyses. Myopia progression varied systematically by month; it was slower in April through September than in the other months. Mean progression in winter was −0.35 ± 0.34 D and in summer was −0.14 ± 0.32 D, a statistically significant difference (0.21 D, $P < 0.0001$). The same seasonal pattern was found by age, sex, ethnicity (except in the small sample of Asians), lens type, and clinical center.

Conclusions. The slower progression of myopia found in summer is likely related to children's spending more time outdoors and fewer hours in school. The data have clinical implications regarding the time of year and the frequency with which myopic children have eye examinations and the need for precise timing of visits in clinical trials testing new myopia treatments. (ClinicalTrials.gov number, NCT00000113.)

Keywords: myopia, refractive error, children's vision

The prevalence of myopia has increased dramatically over the past few decades, suggesting a role for environmental factors.[1,2] The environmental factor cited most frequently in the past was excessive near work and schooling (reviewed in Ref. 3). Recently, differences in outdoor activity, especially light exposure, have emerged as a potential key factor to account for differences in the refractive errors of children, including the reduced prevalence and incidence of myopia in children with more outdoor activity.[4–12]

A study of Chinese children living either in Sydney or in Singapore provides evidence for the role of outdoor light exposure in refractive development.[13] The Sydney children had a significantly lower prevalence of myopia, and the most significant lifestyle factor associated with the difference in prevalence was time spent outdoors (13.5 hours per week in Sydney versus 3.05 hours per week in Singapore). Additional support for the influence of light on myopia progression comes from a recent paper by Cui et al.,[11] who found less myopia progression and axial elongation in Danish children tested over 6-month periods that included longer summer (versus shorter winter) days. Even though information on each child's actual amount of outdoor light exposure was not collected, the assumption was that children in Denmark spend more time outdoors in the summer than in the winter and therefore the children tested in a 6-month period that included the summer had more outdoor light exposure.

The combination of low levels of near work and long periods of time outdoors is associated with less myopia in children.[8,14] These factors also may account for the reported slower progression of myopia and/or axial elongation in the summer compared to the school year.[15–19] Children in the United States typically are in school from late August or early September until May or June and then have a long summer vacation, usually with a significant increase in outdoor activity and decrease in near work compared to the school year.[5] Indoor hours devoted to school/studying and outdoor activity hours vary dramatically between winter and summer for most children. For example, weekly hours of studying by myopic

Table. Participant Characteristics in the First Year

Characteristic/Variable	Included, $n = 358$		Excluded, $n = 111$		P
	n (%)	Mean (SD)	n (%)	Mean (SD)	
Sex					
Male	167 (46.6)		56 (50.5)		0.48
Female	191 (53.4)		55 (49.5)		
Ethnicity					
Asian	32 (8.9)		4 (3.6)		0.29
African American	91 (25.4)		32 (28.8)		
Hispanic	55 (15.4)		13 (11.7)		
Caucasian	163 (45.5)		55 (49.5)		
Mixed and other	17 (4.7)		7 (6.3)		
Treatment					
PAL	176 (49.2)		59 (53.2)		0.46
SVL	182 (50.8)		52 (46.8)		
Age, y, at baseline		9.84 (1.27)		9.82 (1.36)	0.90
Baseline SE myopia (D)		−2.54 (0.84)		−2.66 (0.82)	0.20

children in Boston, Massachusetts, decreased from 10.8 during the school year to 1.3 in the summer, while outdoor activity hours increased from 8.3 during school to 19.4 in the summer.[5] It should be noted that these hours do not include time in school, which for children in Boston averaged 30 hours per week. Therefore, available hours for outdoor activity are more limited during the school year.

The previous studies investigating seasonal progression of myopia have reported results from relatively small numbers of children in the United States, southern China, and Japan.[15–19] The Correction of Myopia Evaluation Trial (COMET) recruited 469 myopic children for a study of spectacle lens treatments for myopia control, with recruitment occurring throughout the year.[20] Progression of myopia in COMET was found to be faster in younger children; in girls; and in Asian, Hispanic, and white children compared to African Americans.[21] However, progression of myopia by month or season of the year was not investigated and is the purpose of the current study. The large dataset allows for a more fine-grained analysis of myopia progression by time of year than in previous reports.

Methods

Details of the study design and main outcome of the clinical trial have been published previously and are briefly summarized here.[20–22] The COMET study enrolled 469 6- to <12-year-old children with myopia between −1.25 and −4.50 diopters (D), with half randomized to single vision lenses (SVLs), the conventional treatment for myopia, and half to progressive addition lenses (PALs). Study visits were scheduled every 6 months for the first 5 years. The main outcome after 3 years (the length of the clinical trial) was a 0.20 D treatment benefit of PALs, with 98.5% retention.[20] Four colleges/schools of optometry participated in COMET; they were located in Boston, Massachusetts; Birmingham, Alabama; Houston, Texas; and Philadelphia, Pennsylvania. The institutional review boards at all participating centers approved the research protocols, and the research followed the tenets of the Declaration of Helsinki. Informed consent from the parents was obtained after verbal and written explanation of the study, and assent was obtained from the children.

The ARK 700A (Nidek, Gamagori, Japan) autorefractor/autokeratometer was used to take five consecutive, reliable refraction readings, which were then averaged. Noncycloplegic autorefraction measurements were used in the present analyses because they were taken every 6 months in contrast to the main outcome measure of myopia progression by cycloplegic autorefraction, which was taken only annually. The mean (±SD) difference between the cycloplegic and noncycloplegic measurements at baseline was 0.19 ± 0.22 D.[22]

Right eye data from children with seven semiannual visits over 3 years and with measurements within ±35 days of their targeted visit dates were used. The semiannual progression rate was calculated as: (change in spherical equivalent refraction [SER] between two consecutive semiannual visits/number of days between the two visits) × 182.5. Months were categorized as the midpoint between two visit dates; for example, January includes progression from October to April. Seasons were classified as winter (October through March) or summer (April through September). The seasonal difference was tested using a linear mixed model adjusting for demographic variables (age, sex, and ethnicity), baseline refraction, and treatment group.

Results

Data from 358 of 469 participants (76.33%) met the criteria for this study. Baseline characteristics of included and excluded children were similar, as shown in the Table. The mean (±SD) age of the children used in these analyses was 9.84 ± 1.27 years, and their mean myopia was −2.54 ± 0.84 D. The group was ethnically diverse, and 53% were female. Two hundred twelve of the children had summer visits followed by winter, while 146 had winter visits first.

Figure 1 shows the semiannual progression rate by month in the first year of the study. The progression varied systematically by month; it was slower in April through September than in the other months. Mean progression in winter (dark bars in Fig. 1) was −0.35 ± 0.34 D and in summer was −0.14 ± 0.32 D, a statistically significant difference (0.21 D, $P < 0.0001$). As shown in Figure 2, the seasonal progression did not vary by age (interaction between age groups and season, $P = 0.54$). In addition, similar seasonal patterns were found for all ethnic groups except Asians (Fig. 3), with borderline significance for the interaction between ethnicity and season ($P = 0.08$). Because ethnic groups were not balanced across the four clinical centers, the data by center are

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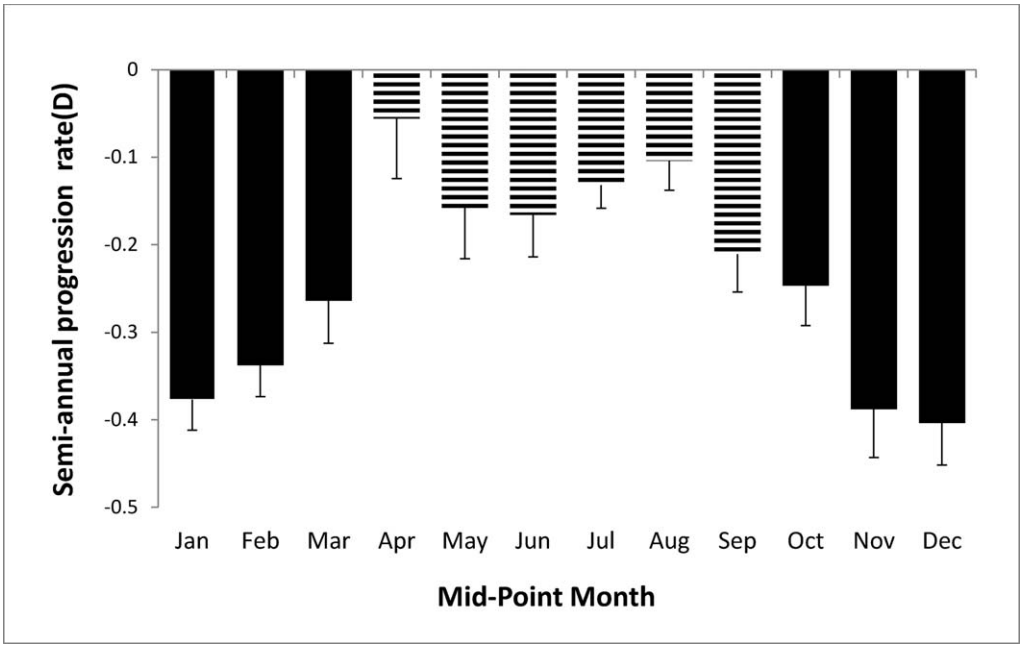

Figure 1. Semiannual progression rate by midpoint month in the first year of COMET. Winter months are shown by *dark bars* and summer months by *hatched bars*.

shown only for Caucasian children in Figure 4, with similar seasonal patterns found at all centers. Seasonal differences also were found when the data were analyzed by sex and by lens type, SVLs or PALs (data not shown). The overall seasonal difference was slightly higher for children with first visits in the winter (0.24 D difference) than in the summer (0.18 D difference), but not statistically significant ($P = 0.30$). Figure 5 shows that a similar seasonal pattern of myopia progression was found in the second and third years of the study, with statistically significant differences ($P < 0.0001$ for each year).

Discussion

The large number of myopic children in COMET and their ethnic diversity allow for more detailed analyses of progression of myopia by time of year than in previous studies. Monthly differences in myopia progression in children are reported here for the first time, with greater progression in winter compared to summer months. Exposure to higher light levels and reduced academic pressures in the summer are likely to account for the slowed progression over the summer months found in the current study. The present data are consistent with results of a recent study by Cui et al.,[11] who found less myopia progression and axial elongation in Danish children tested over 6-month periods that included summer days. It should be noted that the current method of averaging across 6 months and attributing the data to the most central month, used in this and some other studies, likely underestimates the actual monthly differences.

In the present study, seasonal differences in progression of myopia were found when the data were stratified by age, sex, treatment group, and ethnicity, except possibly for Asian children (*P* value for interaction between ethnicity and seasonal progression was of borderline significance). While

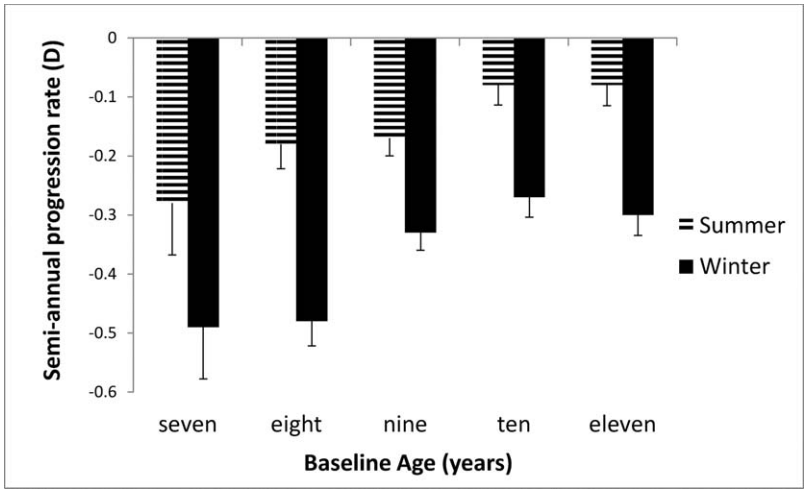

Figure 2. Semiannual progression rate in winter and summer stratified by age in the first year of COMET. Winter months are shown by *dark bars* and summer months by *hatched bars*.

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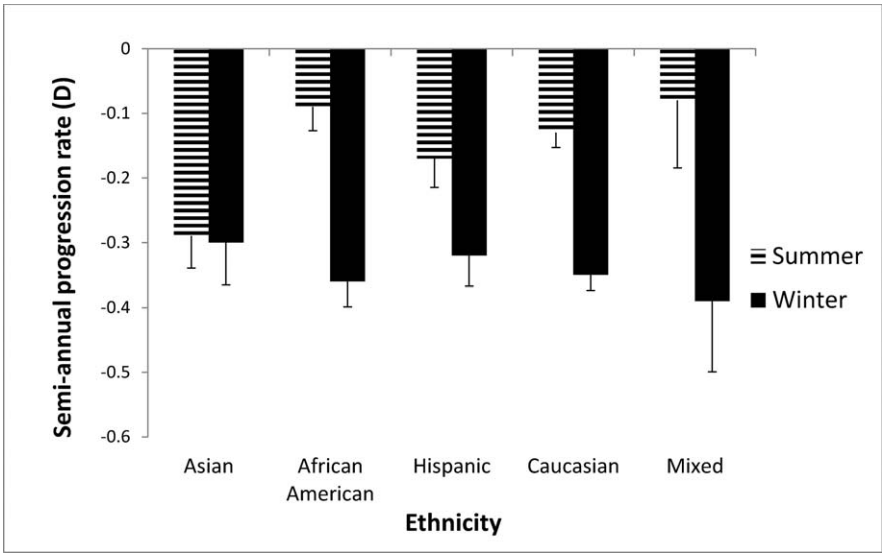

Figure 3. Semiannual progression rate in winter and summer stratified by ethnicity in the first year of COMET. Winter months are shown by *dark bars* and summer months by *hatched bars*.

reasons to account for the latter result are not known, one possibility is that these children have heavy educational commitments during both the school year and the summer, resulting in limited time outdoors year round, similar to the low number of outdoor hours shown for Chinese children living in Singapore.[13] Similar seasonal progression patterns also were shown at the four COMET clinical centers, two in the Northeast and two in the southern United States. These locations have different hours of daylight depending on the time of year, resulting in a range of differences in daylight hours between the longest and shortest days of the year, from a high of 6.12 hours in Boston, which has the shortest winter days and longest summer days, to 5.41 hours in Philadelphia, 4.27 hours in Birmingham, and 3.49 hours in Houston (downloaded on October 9, 2013 from http://www.timeanddate.com/worldclock/sunrise.html [in the public domain]). In addition to the different hours and intensity of light depending on the time of year, the climate at each location also has to be considered. Children are less likely to be outside on summer days in Houston or Birmingham, locations with high heat and humidity, than on summer days in Boston or Philadelphia.

Similar seasonal differences in myopia progression have been reported in studies conducted in various places in the United States and also in different locations and latitudes around the world (and therefore with different photoperiods), as shown in Figure 6. To illustrate this point, in Guangzhou, China, the location of a recent study by Donovan et al.,[15] seasonal differences in hours of daylight are small (10:52 hours of daylight in mid-January and 13:25 in mid-July, as reported in the paper) compared to most study locations in the United States, and yet the summer–winter differences in myopia progression are similar. The results presented in Figure 6 suggest that light is not likely to be the only factor affecting myopia progression.

Results of animal studies point to a role for light in protecting eyes from axial elongation and the development of myopia. Experiments on chicks, tree shrews, and infant monkeys showed that higher ambient light levels were associated with slower development of form-deprivation

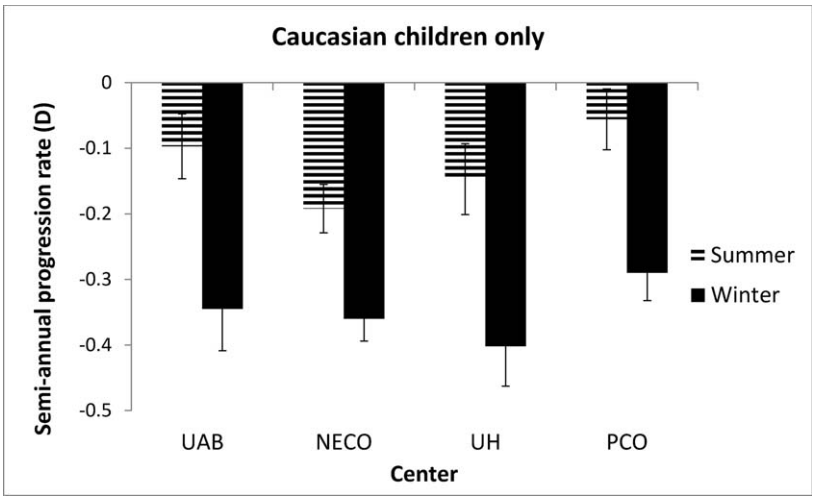

Figure 4. Semiannual progression rate in winter and summer in white children stratified by clinical center in the first year of COMET. Winter months are shown by *dark bars* and summer months by *hatched bars*.

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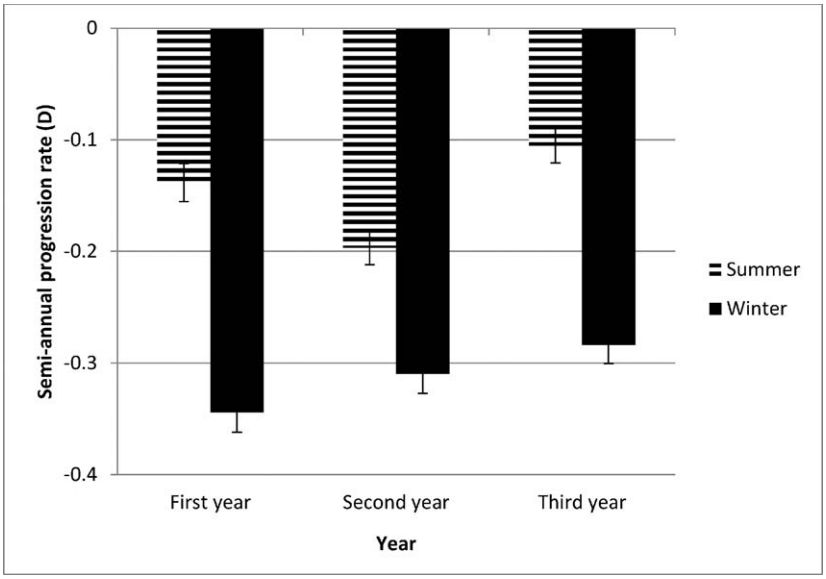

Figure 5. Semiannual progression rate in winter and summer over the first 3 years of COMET. Winter months are shown by *dark bars* and summer months by *hatched bars*.

myopia and, in chicks and tree shrews, were associated with a slower rate of myopia development in response to negative-lens wear.[23–27] The higher light levels did not prevent negative lens–induced myopia from reaching full compensation; however, a negative lens provides a refractive target to which animal eyes respond. Although human emmetropization is known to be regulated by defocus, underaccommodation does not provide a fixed target and, in this one respect, may be analogous to the situation imposed by form deprivation in animals.[27] Thus, the slowed responses of both negative lens–induced myopia and form-deprivation myopia during exposure to higher light intensities provide support for a light-based explanation for the observed monthly and seasonal differences in myopia progression in children.

It is difficult to reconcile the present results and others suggesting that progression of myopia is modulated seasonally with the absence of an association between outdoor activity or near work and myopia progression using questionnaire data in the CLEERE study.[28] Possible reasons to account for the latter result include a limited range of outdoor activity shown by the myopic children, data collection only for activities done in the school year, the combination of sports and outdoor activity in the questionnaire, and possible statistical limitations.

Strengths of the current study include the large, ethnically diverse sample of myopic children with standardized measurements of refractive error taken at regular intervals. Limitations include the use of noncycloplegic autorefraction measurements, which were taken every 6 months, rather than cycloplegic autorefraction, which was done only annually, though in this group of myopic children these measurements were very similar. In addition, axial length was measured only

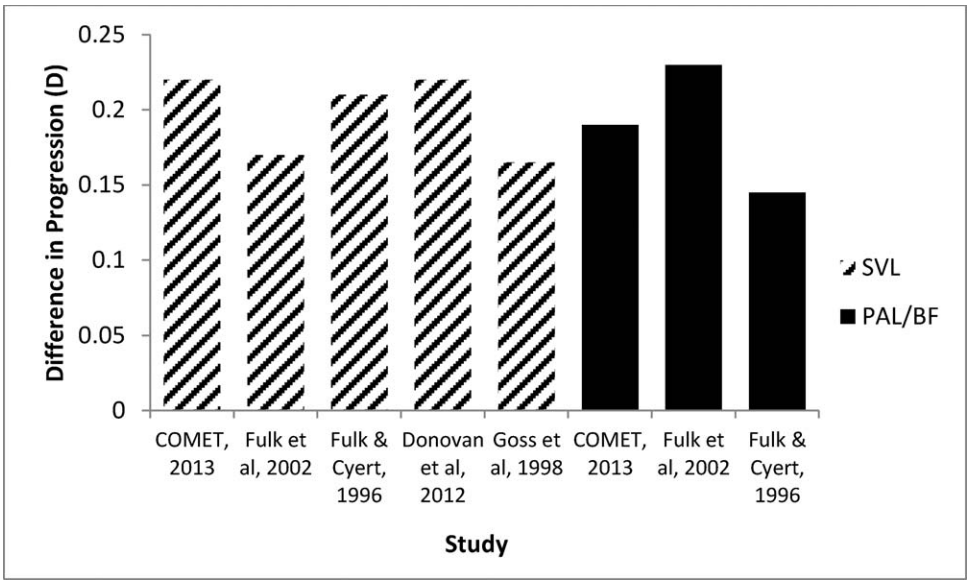

Figure 6. Comparison of COMET seasonal progression of myopia (winter–summer) with other studies using either single vision lenses (*hatched bars*) and/or PALs/bifocals (*dark bars*).

annually in COMET, so those data could not be included in the seasonal analyses.

The current data showing differences in myopia progression by time of year have clinical implications, suggesting that it is important to consider the time of year and the frequency with which myopic children have eye examinations. Children in the United States typically get eye examinations at the end of summer before school starts or at the beginning of the school year when the child fails a school vision screening. New spectacles or contact lenses in the autumn and more rapid progression occurring at the same time mean that many children could be undercorrected soon after school starts, and undercorrection has been shown to increase myopia progression by a small amount compared to full correction.[29,30] Therefore, it would be optimal for myopic children, especially those younger than 9 years of age and/or with two myopic parents (the groups with faster progression),[21] to be examined more frequently than once a year as is now recommended. Parents and teachers should encourage more outdoor play and less near work (though not to the point of affecting school performance), especially during the school year when myopia progression is greater. With respect to clinical trials testing new treatments for myopia control, researchers should consider carefully the time of year for recruitment of patients and the duration of the study. Finally, it is important to note that the current results are relevant to strategies for the prevention of high myopia and its attendant complications. More time spent outdoors and less time indoors doing near work may slow axial elongation and prevent high myopia, thereby reducing the risk of developing sight-threatening conditions such as retinal detachments and myopic retinopathy.

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Appendix

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