

Full Length Research Paper

Ocular component characteristics of Chinese emmetropic children

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Purpose to describe the ocular components of Chinese emmetropic children and determine if accommodation has long term effects on eye elongation. Autorefractometry after cycloplegia was performed on 428 children (ages 3 - 14). 273 eyes met emmetropia the refractive error requirement for emmetropia (between +1.0 D and -0.5 D). Participants were divided into three groups: pre-school children (≤ 6 years old, group 1), grade school children (7 - 10 years old, group 2) and middle school children (>10 years old, group 3). Ocular components were measured using autorefractometry and A-scan ultrasonography. When considering all subjects, there was a negative correlation between age and corneal power ($r = -0.227$, $p = 0.0001$), lens thickness ($r = -0.263$, $p = 0.00001$), and Gullstrand lens power ($r = -0.452$, $p << 0.0001$). There was a positive correlation between age and axial length ($r = -0.432$, $p << 0.0001$) and vitreous chamber depth ($r = 0.505$, $p << 0.0001$). Mean corneal power ($p < 0.001$) and lens power ($p < 0.001$) were significantly greater in pre-school children than in grade school children, while axial length ($p < 0.001$) and vitreous chamber depth ($p < 0.001$) were significantly greater in grade school children. Mean lens thickness ($p = 0.01$) and lens power ($p = 0.07$) were higher in grade school children than in middle school children, while axial length ($p = 0.024$) and vitreous chamber depth ($p < 0.001$) were higher in the middle school children. Ocular components may play different roles in emmetropization. In pre-school children, decreases in corneal power and lens power compensate for the increased axial length. In the grade school and middle-school children, decreases in lens power and lens thickness compensate for the change. Naturally occurring accommodation can also be caused by vision intensive schoolwork which could potentially lead to increased eye size.

Key words: Accommodation, eye elongation, ocular component, emmetropization.

INTRODUCTION

The process in which refractive error variability decreases and hyperopia is lost during childhood is called emmetropization. Rapid emmetropization takes place in the early phase of life. One reason for the accelerated emmetropization is the rapid growth of the eye in infants. There is a significant decrease in refractive error between 3 and 9 to 12 months of age followed by a period of little change until 3 years of age (Mutti et al., 2004). Between 3 and 9 months of age, axial length increases and reaches up to 90% of the average length at age 6 (Zadnik et al., 2003). After age 3, a slow ten-year growth period occurs.

In addition to axial length, the cornea and crystalline lens could be important contributors to emmetropization, perhaps playing different roles in different phases of life. While reports on the ocular component characteristics of emmetropic school-aged children are available, little research has been done on emmetropic pre-school children. The precise mechanisms coordinating the optical and structural development of the eye are not completely understood. The current model of human emmetropization was developed from animal studies and states that hyperopic defocus caused by hyperopic retinal blur modulates eye growth to reduce refractive error (Smith and Hung, 1999; Wildsoet, 1997). Drexler et al., 1998 found that eye elongation can be caused by the which results in accommodation-induced contraction of the ciliary muscle

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Table 1. Study sample by sex and age.

Age	Sex					
	Male		Female		Both	
	N	%	N	%	N	%
3	4	50.0	4	50.0	8	2.9
4	10	47.6	11	52.4	21	7.7
5	12	48.0	13	52.0	25	9.3
6	15	46.9	17	53.1	32	11.7
7	16	47.1	18	52.9	34	12.4
8	18	50.0	18	50.0	36	13.2
9	11	47.8	12	52.2	23	8.4
10	18	51.4	17	48.6	35	12.8
11	9	45.0	11	55.0	20	7.3
12	10	50.0	10	50.0	20	7.3
13	5	50.0	5	50.0	10	3.7
14	4	44.4	5	55.6	9	3.3
All	132	49.7	141	50.3	273	100.0

forward and inward pulling of the choroid, thereby decreasing the circumference of sclera and leading to increased axial length. This elongation represents a short term effect of accommodation.

Children are burdened with different amounts of vision intensive academic work, especially in China where reading and writing requirements are high for school-aged children. Academics become more demanding in middle school, where reading and writing requirements increase. Because such vision activities require accommodation and accommodation induces eye elongation, there may be differences between the ocular component of pre-school and school-aged children. This study measured the ocular components of Chinese emmetropic children aged 3 to 14 years to determine if accommodation causes long term effects on eye elongation.

METHODS

A visual study program was conducted in July 2006 which included 428 pre-school children and school-aged children from kindergartens, grade schools and middle schools. Parents of eligible children provided informed consent according to the Tenets of the declaration of Helsinki. Participants had no history of difficulty with eye drops, no history of seizures and no abnormal condition from slit-lamp examination before further inspection. This report presents data collected as part of the program.

Ocular axial dimensions were measured using A-scan ultrasonography (Humphrey Model 820). Recorded measurements consisted of the average of five valid readings using a handheld probe on semiautomatic mode. To facilitate the measurements, topical 0.5% Dicaïne eye drops was used to anesthetize the cornea. After the examinations were finished for the first visit, 1% Atropine eye drops was used to induce pupillary mydriasis (three times per day for three days).

The autorefractor (ARK-700A, NIDEK) was used to measure corneal power and investigate the refractive error after cycloplegia. Emmetropia was defined as a refractive error (spherical equivalent) between +1.0 D and -0.5 D. A total of 273 eyes met this criterion.

Participants were between 3 and 14 years of age and only one eye per participant was included. Participants were divided into three groups; pre-school children (age ≤ 6 years old, group 1), grade school children (7 - 10 years old, group 2) and middle school children (age >10 years old, group 3). Mean academic work time of the three groups was 2, 6 and 9 h/day respectively. Axial length, anterior chamber depth, corneal power and aqueous humor refractive index were used to define the Gullstrand lens power. Sigmaplot v8.0 was used to create the graphs presented in this report.

STATISTICAL METHODS

Statistical analysis was performed using Sigma Stat 3.0. A Shapiro-Wilk test was used to confirm normal distribution. T-tests were performed to determine if there were statistically significant differences in ocular components between groups 1 and 2 and between groups 2 and 3. If data did not display normal distribution, a Mann-Whitney rank sum test was used. When analyzing correlations between age and ocular components, a Perason's product-moment correlation test was used for normally distributed data. If data were not normally distributed, a Spearman's rank correlation test was used. A significance level of $\alpha = 0.05$ was used for all analyses.

RESULTS

Sample distributions are presented in Table 1. Across the age range, there was a negative correlation between age and corneal power ($r = -0.227$, $p = 0.0001$), lens thickness ($r = -0.263$, $p = 0.00001$) and Gullstrand lens power ($r = -0.452$, $p << 0.0001$). There was a positive correlation between age and axial length ($r = -0.432$, $p << 0.0001$) and vitreous chamber depth ($r = 0.505$, $p << 0.0001$). No correlation was observed for anterior chamber depth ($p = 0.812$, Figures 1A-F).

There were significant differences between groups 1 and 2 in corneal power ($p < 0.001$), axial length ($p < 0.001$), anterior chamber depth ($p = 0.007$), vitreous chamber depth ($p < 0.001$), and Gullstrand lens power ($p < 0.001$). Mean corneal power and Gullstrand lens power were higher in group 1 (Table 2). Axial length, anterior chamber depth and vitreous chamber depth were higher in group 2 (Table 2, Figures 2A-F).

There were significant differences between groups 2 and 3 in axial length ($p = 0.024$), lens thickness ($p = 0.01$), vitreous chamber depth ($p < 0.001$), and Gullstrand lens power ($p = 0.007$). Mean lens thickness and Gullstrand lens power were higher in group 2, while axial length and vitreous chamber depth were higher in group 3 (Table 2, Figures 2A-F).

DISCUSSION

During the first year of life, increasing axial growth produces a net loss of hyperopia, despite decreases in both corneal and lenticular power. It is during this first year that the majority of refractive error change appears to take place.

Cross-sectional and longitudinal data suggest that most emmetropization takes place between 3 and 12 month of age as no significant difference in spherical equivalent

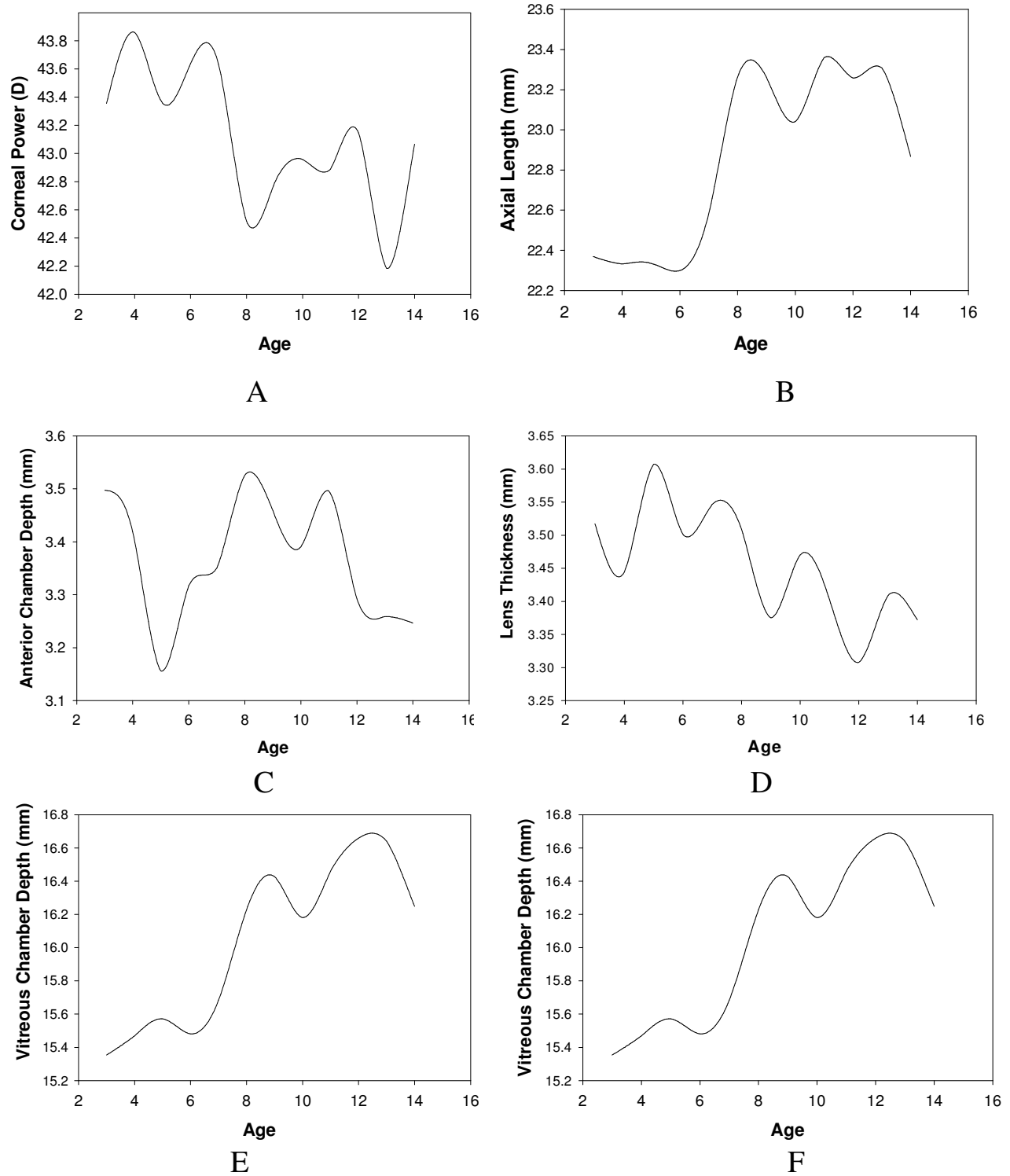


Figure 1. Changes in ocular components as a function of age.

refractive error is found between 9 and 36 months of age (Pennie et al., 2001; Mohindra and Held, 1981; Mayer et al., 2001). After the rapid emmetropization between 3 and 12 months of age, few changes in the eye directed towards

emmetropization occur. The slow growth of the eye is closely coordinated with changes in lens power and corneal power until a balance is reached.

Animal studies suggest that coordinating the optical and

Table 2. Mean optical component values for groups 1, 2 and 3. Values are given as mean \pm standard deviation.

Ocular Component	Group 1(n=86)	Group 2(n=128)	Group 3(n=59)
Refractive error (D)	0.55 \pm 0.38	0.44 \pm 0.42	0.19 \pm 0.49
Corneal power (D)	43.59 \pm 1.17	42.98 \pm 1.34	42.88 \pm 1.15
Axial length (mm)	22.32 \pm 0.60	23.02 \pm 0.72	23.34 \pm 0.70
Lens thickness (mm)	3.31 \pm 0.27	3.43 \pm 0.27	3.35 \pm 0.35
Anterior chamber depth (mm)	3.52 \pm 0.23	3.48 \pm 0.19	3.37 \pm 0.18
Vitreous chamber depth (mm)	15.49 \pm 0.61	16.11 \pm 0.66	16.53 \pm 0.73
Gullstrand lens power (D)	21.55 \pm 1.63	20.03 \pm 1.54	19.25 \pm 1.58

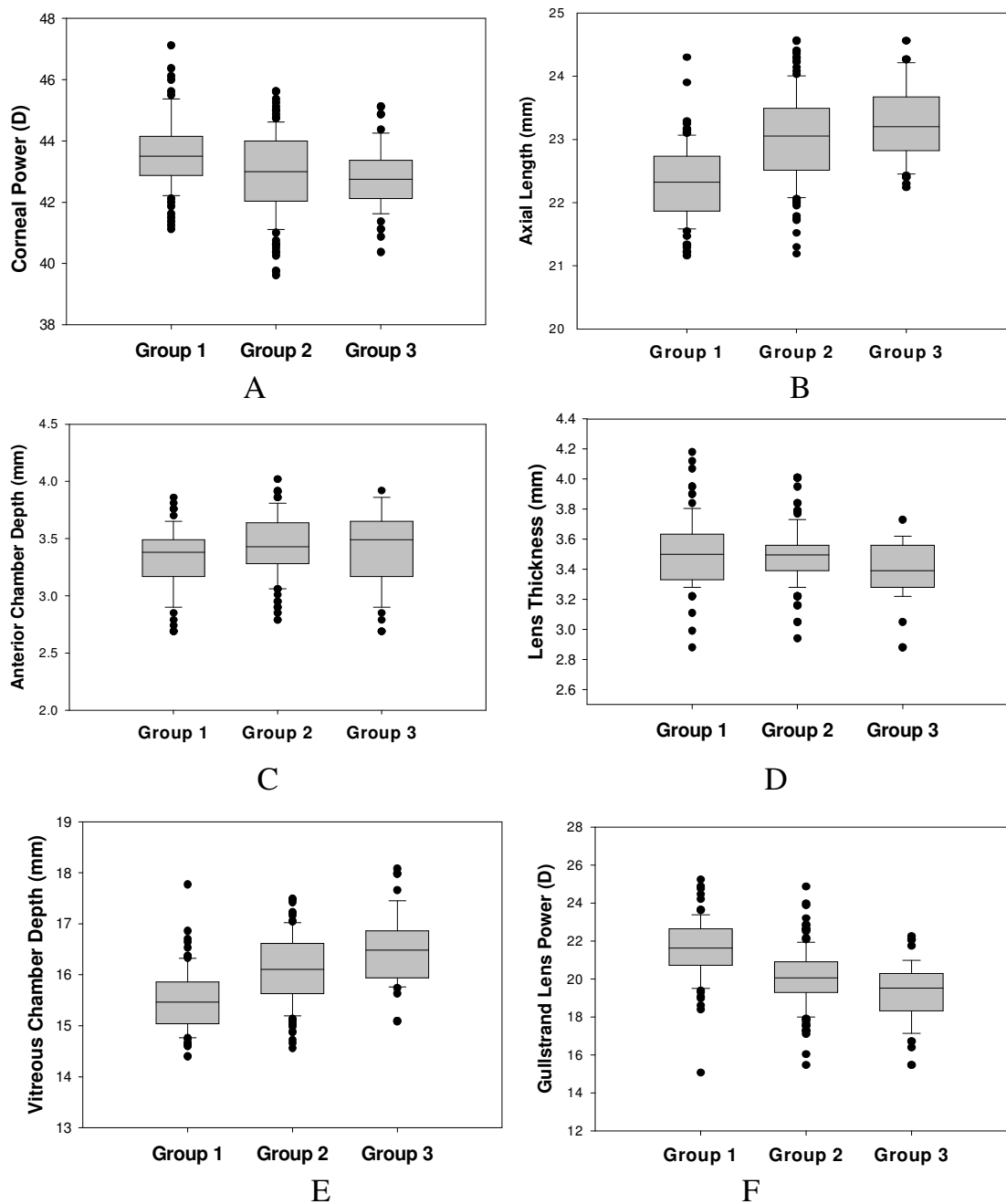


Figure 2. Box plots displaying ocular component characteristics for each group.

structural development of the eye is guided by feedback from visual input (Smith and Hung, 1999; Schaefel et al., 1988; Irving et al., 1992; Wildsoet and Wallman, 1995;

Wallman et al., 1995). The visual feedback model of emmetropization holds that hyperopic defocus modulates the axial growth of the eye to reduce retinal blur. Visual guidance of ocular growth might therefore be termed an "active" mechanism. Emmetropization could also result from the loss of anterior segment power at different rates depending on initial retinal blur. This type of optical coordination between lenticular power change, corneal power change and initial retinal blur might be termed "passive" as visual guidance of axial growth would not be necessary (Mutti et al., 2005). Though the role ocular components play in emmetropization is not completely understood, it is proposed that axial length, corneal power and crystalline lens power could be important contributors to emmetropization.

Based on a combination of cross-sectional and longitudinal study on the emmetropic school-aged children from 6 to 15 years age, Zadnik et al., 2004 demonstrated that the hallmarks of the ocular components are axial elongation, crystalline lens flattening and thinning, and a decrease in lens power. Corneal power changed little across this period. Our study which included pre-school and school-aged children showed that in addition to an axial elongation and decreased lens power, corneal power also decreased significantly. If corneal power plays a role in coordinating emmetropization, axial length and lens power would change accordingly. Few published studies have divided emmetropic children according to grade level when analyzing ocular components characteristics. This is done in our study, providing a more comprehensive picture of how ocular components change.

Significant differences were observed for axial length, lens power and corneal power between the pre-school and grade school children. Axial length was 0.7 mm greater in grade school children. If one assumes a conversion factor of 2.67 D/mm of eye length (based on calculations using the Gullstrand 1 schematic eye), this translates to 1.87 D of dioptric power. Thus, if the developing emmetropic eye were to grow only from front to back, these emmetropes would become nearly -2.0 D myopes by the time they were 10 years old. However, the decreasing power of the crystalline lens (1.52 D) and cornea (0.61 D) balance the axial elongation to maintain emmetropia. Significant changes in axial length and lens power were also observed between grade school and middle school children. A decrease of 0.78 D in lens power compensated for the increase of 0.32 mm in axial length. Had the decrease in lens power not occurred, the children would have been -0.85 D myopes by age 14. Corneal power had little effect on coordinating the emmetropization in the middle school children. This was consistent with previous cross-sectional and longitudinal studies on emmetropes (Friedman et al., 1996; Grosvenor and Goss, 1998).

Axial growth correlates inversely with changes in cor-

neal and crystalline lens power, but question arises about which component drives the coordinated development. There are at least two possible mechanisms. Equatorial expansion of the eye creates a flatter, less powerful cornea and lens. Alternatively, intrinsic power losses of the cornea and lens create hyperopic defocus that stimulates continued eye growth. The first potential mechanism is based on van Alphen size and stretch factors (Van, 1961). According to this model, the cornea becomes flatter because of the increased eye size and the lens flattens due to the equatorial stretch. The second mechanism follows from animal models of active emmetropization. Because our study showed that little change in corneal power occurred in the middle school children, it is not reasonable to conclude that decreased corneal power would create hyperopic defocus which would stimulate eye growth. Both our study and the study conducted by Zadnik et al., 2004 support the first mechanism. It is accepted that the size of the eye would increase slowly after 3 years of age.

However, in our study, axial length changed significantly between pre-school and grade school children, as well as between grade school and middle school children. Because the three groups had different amounts of academic work which demands accommodation, we can conclude that accommodation play a role in regulating how eye size increases during childhood. Accommodation-induced eye elongation is caused by a choroidal effect, a scleral effect or a combination of both. One possible mechanism of how eye elongation occurs during accommodation could arise directly from the contraction of the ciliary muscle. This muscle consists of a ring of smooth muscles adjacent to the inner surface of the anterior sclera (Moses, 1987), is effectively continuous with the choroids (Alpem, 1969) and is comprised of fibers which originate at the corneoscleral spur and insert at Bruch's membrane (Rohen, 1979). Contraction of the ciliary muscle results in a maximum force of 5 mN (Lograno and Rchibaldi, 1986) and an axipetal displacement (that is, forward and inward) of the zonular attachment, with a forward pulling of the choroid (Moses, 1987), thus possibly decreasing the circumference of the sclera, leading to an elongation of the posterior segment and consequently, an increase in axial length.

Our study and previous studies (Zadnik et al., 2004), confirm that the cornea does not display dioptric changes in school-aged children. The lens is thinner in school-aged children and more likely plays a role in emmetropization during this period. An emmetropization mechanism incorporating decreasing lens thickness would result in overall growth of the eye in the axial and equatorial directions. In this model, accommodation-induced ocular growth could result in equatorial crystalline lens stretching, resulting in decreased lens thickness as school-aged children undergo a period of coordinated ocular growth. Even though lens growth would occur during this time, equatorial stretching could result in marked lens thinning and may

prevent axial lens thickening.

To investigate the mechanism underlying changing ocular component characteristics further, a longitudinal study is warranted. If school-aged children in this cross-sectional study exhibited high hyperopia during their pre-school years, eye elongation could have been induced by the hyperopic defocus. Changes in corneal power and lens power could potentially have resulted from this eye elongation. Additionally, future studies could examine the long term effects of accommodation-induced eye elongation.

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