Longitudinal Changes in Spherical Equivalent of Moderate to High Hyperopia: 2- to 8-Year Follow-Up of Children at an Initial Age of 5.5 to 8.4 Years

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PURPOSE. Moderate to high hyperopia is associated with visual deficits. Currently, to our knowledge no study has reported its longitudinal refraction change in a large sample of schoolchildren. We investigated the longitudinal changes in spherical equivalent (*SE*) refractive error among schoolchildren with moderate to high hyperopia.

METHODS. Medical records of patients seeking refractions at Zhongshan Ophthalmic Center between 2009 and 2017 were reviewed retrospectively. Eligible criteria included hyperopia $\geq +2.00$ diopters (D) at an initial age of 6 to 8 years, at least three visits, and at least a 2-year follow-up. Individual pattern of refraction development was evaluated based on the mean rate of change in *SE*. Mixed-effect regression analysis was used to explore factors associated with the rate of change.

RESULTS. A total of 1769 cases were identified. Median initial age was 6.4 (interquartile range [IQR], 5.9 to 7.1) years and median age at the final visit was 10.1 (IQR, 8.9 to 11.5) years. Median initial *SE* was +3.13 (IQR, +2.38 to +5.25) D. On average, participants experienced a myopic shift of -0.35 ± 0.27 D/year. A considerable number of eyes (721, 40.8%) demonstrated a longitudinal change of less than ± 0.25 D/year and approximately 1 of 3 (611/1769) eyes demonstrated a change of > -0.50 and ≤ -0.25 D/year. Children with greater initial hyperopia ($\beta = -0.02$, $P < 0.001$) experienced significantly faster reduction in hyperopic refraction. Age and sex had statistically significant but clinically insignificant impacts on the rate of hyperopia reduction.

CONCLUSIONS. Variation exists in the refraction development of schoolchildren with moderate to high hyperopia. A considerable percentage of eyes demonstrates longitudinally stable refraction.

Keywords: hyperopia, schoolchildren, refraction change, longitudinal

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Hyperopia is a common refractive state among young schoolchildren. Based on a definition of spherical equivalent (*SE*) refractive error $\geq +2.00$ diopters (D), the prevalence of hyperopia has been reported to vary from 2.4% to 13.2% among children aged 6 years, depending on the populations studied.[1–6] Increasing evidence suggests that moderate to high hyperopia is associated with greater risks of visual deficits, including reduced visual acuity[7,8] and stereoacuity.[1,8,9] Prevalence of other ocular conditions, such as amblyopia,[1,9,10] strabismus,[1,9,11] anisometropia,[9] astigmatism,[9] reduced accommodative response,[8] and abnormal convergence,[1] has been reported to be greater among hyperopic children compared to those with emmetropia. Moreover, impaired performance on academic-related tasks, including literacy,[12,13] reading,[14,15] and visual information processing,[14] has been proved associated with hyperopic refractive errors in children.

Previous population-based studies have well documented that the prevalence of hyperopia decreased in older schoolchildren.[1–4,16–21] A few longitudinal studies have reported the amount of reduction in hyperopic refraction over time. In the Sydney Adolescent Vascular and Eye Study (SAVES), the 5- to 6-year mean rate of change in *SE* in 80 Australian schoolchildren with baseline *SE* $\geq +2.00$ D and age 6 years was -0.19 D/year

and that of 26 children aged 12 years at baseline was -0.26 D/year.[17] In a clinical sample of 86 Korean children initially aged 3 to 9 years and having hyperopic *SE* $> +0.75$ D, the rate of change in *SE* over a mean follow-up of 11.2 years was -0.26 D/year.[22] Longitudinal refraction evolution and ocular component growth curves of hyperopic eyes have been described using data of the Orinda Longitudinal Study of Myopia (OLSM; 43 eyes with persistent and 253 with emmetropizing hyperopia)[23] and the Singapore Cohort Study of the Risk Factors for Myopia (SCORM; 47 eyes with persistent and 142 with emmetropizing hyperopia).[24] In contrast to the plausible argument that eyes with persistent hyperopia would demonstrate an absence of growth, the studies found that these eyes grew with time at all and the growth patterns of hyperopic eyes shared many similarities with those of eyes with persistent emmetropia.[23,24]

While the previous studies have provided a general picture of how refraction and ocular biometric parameters change over time in schoolchildren with hyperopia, it is unclear how the longitudinal changes would vary among individuals with different characteristics. We investigated the longitudinal changes in *SE* of a group of Chinese schoolchildren with moderate to high hyperopia and explored factors associated with the changes.

METHODS

Study Population

We retrospectively and inclusively reviewed the clinical records of patients seeking refractive error corrections at Zhongshan Ophthalmic Center (ZOC) between 2009 and 2017. Children seeking refractions at ZOC were derived mainly from school-based vision screening programs in Guangzhou and, less commonly, referral from other eye care clinics throughout the country (usually children with significant refractive errors). The vision screening in schoolchildren, particularly, tested uncorrected visual acuity (UCVA) annually and children with UCVA of 20/25 or worse in either eye were recommended for further ophthalmic examinations. For every child visiting ZOC, cycloplegic refraction and best corrected visual acuity (BCVA) were measured unless otherwise refused. Follow-up schedules were recommended at clinician discretion, usually every 6 or 12 months to detect changes in refraction and visual acuity.

At ZOC, cycloplegic refractions were mostly performed using 1% tropicamide or 1% cyclopentolate eye drops for children aged ≥8 years, or using 1% atropine ointment at the first visit of a child younger than 8 years and 1% tropicamide or 1% cyclopentolate at following visits. Considering the confounding impacts of the use of different cycloplegic agents, only cycloplegic refractions obtained using 1% tropicamide or 1% cyclopentolate were analyzed in our study. This approach was considered acceptable because cycloplegic refractions obtained using 1% tropicamide and 1% cyclopentolate have been proved to show no significant difference among schoolchildren with hyperopia.[25]

To define a homogeneous group of children, we limited the initial age to be 6 (range, 5.5–6.4), 7 (range, 6.5–7.4), or 8 (range, 7.5–8.4) years. The first visit occurred between ages 6 to 8 years (inclusive) was defined as the initial visit, and visits thereafter were defined as follow-up visits. Eligible criteria were: having cycloplegic refraction measured at the age of 6, 7, or 8 years; presenting SE (calculated as spherical power plus 1/2 cylindrical power) ≥+2.00 D and interocular SE difference <1.00 D at the initial visit; being followed for a minimum of 2 years since the initial visit and having at least three records on cycloplegic refractions; absence of any other ocular conditions, including aphakia, strabismus, nystagmus, and amblyopia (for the age range in our study, satisfying the following: presence or a history of at least one amblyogenic factor; presenting BCVA ≤ 20/40 in either eye or an interocular difference in BCVA of two or more lines after wearing optimal optical correction for a minimum of three months; and no cause for reduced visual acuity suspected other than amblyopia); and absence of any concurrent systemic disorders, such as developmental delay. The study was approved by the ethics committee of Zhongshan Ophthalmic Center, Sun Yat-sen University, Guangzhou and conducted in accordance with the Declaration of Helsinki.

Refraction Measurement and Spectacle Prescription

Cycloplegic refractions were obtained by 23 trained optometrists according to a standardized protocol.[26] Cycloplegia was achieved using three successive 1% tropicamide or 1% cyclopentolate eye drops instilled 5 minutes apart. Refraction was measured after complete cycloplegia (determined by the absence of light reflex and a dilated pupil at least 6 mm in diameter) was achieved and at least 30 minutes after the last administration of cycloplegic drugs. Cycloplegic retinoscopy was performed before measurements of subjective refractions and retinoscopy results were used as starting points of subjective refraction assessments. The spherical endpoint of subjective refraction was determined to be the most hyperopic

spherical power providing best visual acuity. The Jackson cross cylinder technique was applied to determine the astigmatism among children aged 8 years or older. For children younger than 8 years, the power and axis of astigmatism were taken from the results of retinoscopy. Refractions were recorded in increments of 0.25 D. When the examining optometrist was uncertain about the result, refraction was checked and determined by one of two senior optometrists in charge. At follow-up visits, examining optometrists were masked to patient previous refractions during retinoscopy and subjective refraction measurement.

Spectacle prescriptions were at clinician discretion. Eyes with hyperopic SE ≥+2.00 D or astigmatism >1.00 D were recommended to be prescribed. Other considerations, including symptoms and school performance, also were taken into account. Spectacles were prescribed based on cycloplegic subjective refractions, providing full correction of astigmatism and either full correction or symmetrical undercorrection of hyperopia by no more than +1.50 D.

Definitions

In our study, SE and astigmatism in vector notation (J_0 [Jackson cross-cylinder with axes at 180° and 90°] and J_{45} [Jackson cross-cylinder with axes at 45° and 135°])[27] were calculated using records of subjective refractions. The primary outcome of our study was the rate of change in SE. The mean rate of change in SE was calculated as the difference between the final and initial SE refractive errors divided by the follow-up duration in years. Patterns of refraction development were defined according to the mean rate of change, including refraction stability (mean rate of change in SE, $<\pm0.25$ D/year), mildly myopic shift (mean rate of change in SE, >-0.50 and ≤-0.25 D/year), moderately myopic shift (mean rate of change in SE, >-1.00 and ≤-0.50 D/year), and rapidly myopic shift (mean rate of change in SE, ≤-1.00 D/year).

Statistical Analysis

Because of the high correlation between the right and left eye SEs of the same individual ($r = 0.9825$, $P < 0.0001$, pairwise Pearson correlation test), only data from the right eyes were presented. Initial SE was classified into three categories: ≥+2.00 and <+4.00 D, ≥+4.00 and <+6.00 D, and ≥+6.00 D. Initial J_0 and J_{45} were classified into ≤−0.50 D, >−0.50 and <+0.50 D, and ≥+0.50 D categories. Descriptive statistics were applied. The Shapiro-Wilk test was performed to examine whether variables were normally distributed. Means ± SDs were reported for normally distributed variables and medians (interquartile ranges [IQRs]) were reported for skewed data. Numbers and percentages were reported where appropriate.

The effect of age on the rate of change in SE was examined by fitting the following mixed-effect model:

$$SE_{i,j} = \beta_1 + \beta_2 SE_{i,initial} + (\beta_3 + \beta_4 Age_{i,j})Age_{i,j} + \beta_5 Age_{i,initial} + \beta_6 Method_{i,j} + b_{1i} + b_{2i}SE_{i,initial} + (b_{3i} + b_{4i}Age_{i,j})Age_{i,j} + b_{5i}Age_{i,initial} + b_{6i}Method_{i,j} + \varepsilon_{ij}$$

$$(1)$$

where i refers to the ith child, j refers to the jth follow-up visit; $SE_{i,j}$ refers to the SE of the ith child at the jth follow-up visit; $SE_{i,initial}$ refers to the SE of the ith child at the initial visit; $Age_{i,j}$ refers to the age of the ith child at the jth follow-up visit; $Age_{i,initial}$ refers to the age of the ith child at the initial visit; $Method_{i,j} = 0$ if the ith child received 1% tropicamide at the jth follow-up visit and 1 if 1% cyclopentolate was used; β_1, β_2, β_3,
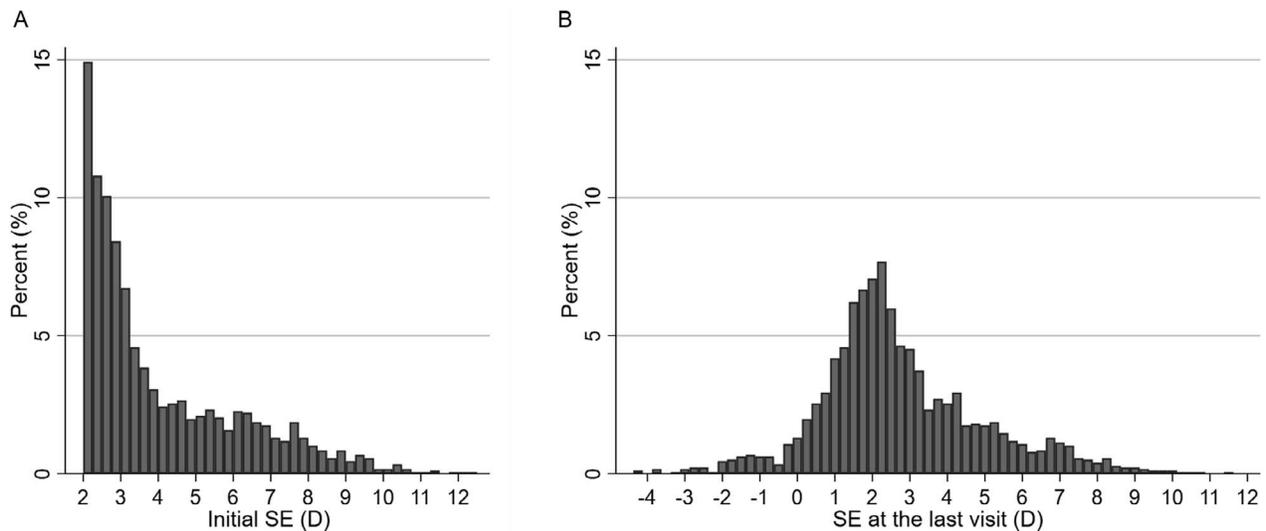
A

B

FIGURE 1. Histograms demonstrating participant initial *SE* (**A**) and *SE* at the last follow-up visit (**B**).

β_4, β_5, β_6 are fixed effects; $b_{1i}, b_{2i}, b_{3i}, b_{4i}, b_{5i}, b_{6i}$ are random effects; and ε_{ij} is random error.

For this model, the $(\beta_3 + \beta_4 Age_{i,j})$ is interpreted as the rate of change in *SE* (D/year) and the fixed effect, β_4, indicates the impact of age on the rate of change. A statistically significant β_4 would indicate that the age had an impact on the rate of change in *SE*.

The mean rate of change in *SE* was calculated by categories of individual initial characteristics. Sex difference in the mean rate of change was examined using the unpaired *t*-test. Trend analysis was performed to detect any differences among different initial *SE* categories and ANOVA was conducted to detect differences among initial J_0 and J_{45} categories. Individual patient profiles, as well as linear mixed-effect regression lines, relating *SE* refractive error with age, were plotted to visualize the longitudinal changes in *SE* in different sex and initial refraction categories. The associations of rate of change in *SE*

with sex and initial *SE*, J_0, and J_{45} were assessed using multivariate mixed-effect regression models. Similar to Model 1 established to examine the effect of age on the rate of change in *SE*, terms of $Age_{i,j}$ multiplied by these characteristics were added to regression models. A statistically significant coefficient of the term would indicate that the characteristic was associated with the rate of change in *SE*.

Numbers and percentages of eyes demonstrating refraction stability, mildly, moderately, and rapidly myopic shift were calculated in the whole population, as well as by sex and initial *SE*, J_0, and J_{45} categories. The distributions are presented as stacked bar graphs and were analyzed by the χ^2 test.

Considering that the pattern of ocular growth would be substantially different when the development of myopia commenced,[23,24,28,29] a secondary analysis was performed, limiting study population solely to those who were nonmyopic (defined as *SE* >−0.50 D) throughout the follow-up period.

TABLE 1. Characteristics of the Study Participants According to Age at the Initial Visit

	Total	Age at the Initial Visit (Years)		
		6	7	8
Number	1769	893	588	288
Median (IQR) age at the initial visit, years	6.4 (5.9, 7.1)	5.9 (5.8, 6.2)	6.8 (6.7, 7.1)	7.8 (7.7, 8.2)
Median (IQR) age at the final visit, years	10.1 (8.9, 11.5)	9.2 (8.4, 10.3)	10.5 (9.6, 12.0)	11.8 (10.8, 13.1)
Median (IQR) of the length of follow-up, years	3.4 (2.6, 4.7)	3.3 (2.5, 4.3)	3.6 (2.8, 5.0)	3.8 (2.9, 5.1)
Sex, boys (%)	1051 (59.4)	529 (59.2)	340 (57.8)	182 (63.2)
Initial *SE*, D				
Median (IQR)	3.13 (2.38, 5.25)	3.00 (2.38, 4.63)	3.25 (2.38, 5.50)	4.06 (2.50, 6.00)
≥+2.00 and <+4.00, *n* (%)	1104 (62.4)	606 (67.9)	357 (60.7)	141 (49.0)
≥+4.00 and <+6.00, *n* (%)	312 (17.6)	136 (15.2)	106 (18.0)	70 (24.3)
≥+6.00, *n* (%)	353 (20.0)	151 (16.9)	125 (21.3)	77 (26.7)
Initial J_0, D				
Median (IQR)	0.75 (0.47, 1.13)	0.82 (0.47, 1.13)	0.79 (0.45, 1.23)	0.70 (0.38, 1.13)
≤−0.50, *n* (%)	7 (0.4)	3 (0.3)	2 (0.3)	2 (0.7)
>−0.50 and <+0.50, *n* (%)	522 (29.5)	250 (28.0)	176 (29.9)	96 (33.3)
≥+0.50, *n* (%)	1240 (70.1)	640 (71.7)	410 (69.7)	190 (66.0)
Initial J_{45}, D				
Median (IQR)	0 (−0.18, 0.13)	0 (−0.17, 0.13)	0 (−0.17, 0.13)	0 (−0.23, 0.09)
≤−0.50, *n* (%)	74 (4.2)	33 (3.7)	28 (4.8)	13 (4.5)
>−0.50 and <+0.50, *n* (%)	1610 (91.0)	821 (91.9)	531 (90.3)	258 (89.6)
≥+0.50, *n* (%)	85 (4.8)	39 (4.4)	29 (4.9)	17 (5.9)

TABLE 2. Mean Rate of Change in *SE* by Participant Characteristics at the Initial Visit

	Mean Rate of Change in *SE* (D/Year)	
	All Children ($n = 1769$)	**Persistent Nonmyopic Children** ($n = 1683$)
Sex		
Boys	-0.33 ± 0.27	-0.31 ± 0.25
Girls	-0.36 ± 0.28	-0.34 ± 0.26
P	0.0269	0.0368
Initial *SE*, D		
$\geq +2.00$ and $< +4.00$	-0.30 ± 0.25	-0.27 ± 0.21
$\geq +4.00$ and $< +6.00$	-0.38 ± 0.29	-0.38 ± 0.29
$\geq +6.00$	-0.45 ± 0.30	-0.45 ± 0.30
P for trend	<0.001	<0.001
Initial J_0, D		
≤ -0.50	-0.04 ± 0.14	-0.04 ± 0.14
> -0.50 and $< +0.50$	-0.40 ± 0.30	-0.39 ± 0.29
$\geq +0.50$	-0.32 ± 0.26	-0.30 ± 0.24
P	<0.001	<0.001
Initial J_{45}, D		
≤ -0.50	-0.37 ± 0.32	-0.32 ± 0.27
> -0.50 and $< +0.50$	-0.35 ± 0.27	-0.33 ± 0.26
$\geq +0.50$	-0.28 ± 0.28	-0.24 ± 0.23
P	0.0866	0.0103

Data are presented as mean $\pm$ SD unless otherwise indicated.

Mean rate of change in *SE*, as well as numbers and percentages of eyes demonstrating refraction stability, mildly, moderately, and rapidly myopic shift, were calculated and compared between sex and initial refraction categories. Multivariate mixed-effect regression analysis was performed to assess the associations of rate of change with sex, *SE*, J_0, and J_{45} at the initial visit. $P < 0.05$ was considered statistically significant. All statistical analyses were performed using STATA version 12.0 (Stata Corporation, College Station, TX, USA) or R (available in the public domain at https://www.r-project.org/).

RESULTS

A total of 1769 cases were identified. Median age at the initial visit was 6.4 years (IQR, 5.9 to 7.1 years), and 1051 (59.4%)
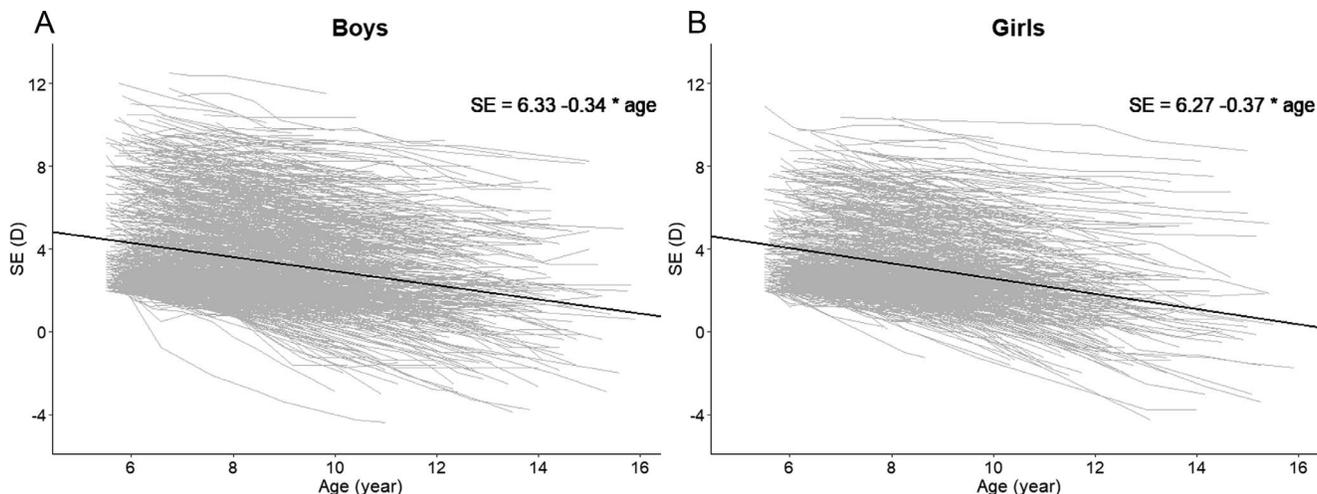
subjects were boys. Study participants were followed for a median of 3.4 years (IQR, 2.6 to 4.7 years), with a maximum of 12 cycloplegic refraction measurements (median, four measurements; IQR, 3 to 5 measurements). Median initial *SE* was $+3.13$ D (IQR, $+2.38$ to $+5.25$ D) and that of initial J_0 and J_{45} was $+0.75$ D (IQR, $+0.47$ to $+1.13$ D) and 0 D (IQR, -0.18 to $+0.13$ D), respectively. Distribution of the initial *SE* is demonstrated in Figure 1A. Detailed characteristics by participant initial age are provided in Table 1.

Figure 1B shows the distribution of *SE* at the last follow-up visit. Eighty-six (4.9%) children developed myopia (*SE* ≤ -0.50 D) during the follow-up period. Their median age at the initial visit was 6.5 years (IQR, 6.1 to 7.3 years) and 49 (57.0%) were boys. Compared to the remaining 1683 children who were non-myopic throughout the follow-up period, children who developed myopia demonstrated lower initial hyperopic *SE* (median [IQR], $+2.31$ [$+2.13$, $+2.75$] D, $P < 0.0001$), more positive initial J_0 (median [IQR], $+0.87$ [$+0.59$, $+1.35$] D, $P = 0.0290$), and were followed up for a longer period of time (median [IQR], 5.9 [4.7, 6.9] years, $P < 0.0001$). Initial age, sex, and J_{45} were not statistically significantly different between the two groups (all $P > 0.1$).

Changes in *SE* With Age

Of all 1769 children, the mean rate of change in *SE* was -0.35 ± 0.27 D/year. The rate of the 1683 children who remained non-myopic throughout the follow-up period was -0.33 ± 0.26 D/year. Among all participants, mixed-effect regression analysis found a small effect of age ($\beta = -0.006$, $P < 0.001$) on the rate of change in *SE*. The association became statistically insignificant ($P > 0.1$) when analyzed in the group of children who remained nonmyopic throughout the follow-up period.

Table 2 shows the mean rate of change in *SE* by participant initial characteristics. Individual *SE* evolution and linear mixed-effect regressions by sex and initial *SE*, J_0, and J_{45} categories are illustrated in Figures 2 to 4. Girls ($\beta = -0.04$, $P < 0.001$) and children with greater initial hyperopic *SE* ($\beta = -0.02$, $P < 0.001$) were associated with more rapid decrease in hyperopia in multivariate mixed-effect regression analysis of all children (terms of $Sex_i \times Age_{i,j}$, $SE_{i,initial} \times Age_{i,j}$, $J0_{i,initial} \times Age_{i,j}$, and $J45_{i,initial} \times Age_{i,j}$ were included; log likelihood of the model was -6444.4 and $P < 0.0001$). Similar associations were found when analyzed among 1683 children who were persistently nonmyopic (for girls and greater levels of hyperopia, both $\beta =$

FIGURE 2. Individual refraction evolutions and estimated linear regression lines of boys (A) and girls (B).

FIGURE 3. Individual refraction evolutions and estimated linear regression lines of children with initial *SE* refractive errors of ≥+2.00 and <+4.00 D (**A**), ≥+4.00 and <+6.00 D (**B**), and ≥+6.00 D (**C**).

Patterns of Refraction Development

Of the all 1769 participants, a total of 721 (40.8%) cases demonstrated refraction stability over the follow-up period. The numbers of children demonstrating mildly, moderately, and rapidly myopic shift were 611 (34.5%), 391 (22.1%), and 46 (2.6%), respectively. Proportions of eyes demonstrating different patterns of refraction development were not statistically significantly different between boys and girls ($P = 0.256$), nor among initial J_{45} categories ($P = 0.171$). Greater proportions of eyes in lower initial hyperopic *SE* categories demonstrated patterns of slower hyperopia reduction ($P < 0.001$, Fig. 5). Eyes in the ≥+2.00 and <+4.00 D initial *SE* category predominantly (533/1104, 48.3%) demonstrated refraction stability over the follow-up period, whereas in the ≥+4.00 and <+6.00 D and ≥+6.00 D categories, the eyes predominantly (37.2% [116/312] for the ≥+4.00 and <+6.00 D category and 38.5% [136/353] for the ≥+6.00 D category) demonstrated mildly myopic shift in the long term. Percentage of eyes demonstrating longitudinally stable refractions in the ≥+4.00 and <+6.00 D category was 33.0% (103/312) and that in the ≥+6.00 D category was 24.1% (85/353). Of seven children with initial $J_0 \leq -0.50$ D, six demonstrated refraction stability and the other one presented mildly myopic shift. Percentage of eyes demonstrating refraction stability was 31.0% (162/522) in the >−0.50 and <+0.50 D initial J_0 category and 44.6% (553/1240) in the ≥+0.50 D category.

Among the 1683 participants who remained nonmyopic throughout the follow-up period, the numbers of eyes demonstrating refraction stability, and mildly, moderately, and rapidly myopic shift were 721 (42.8%), 601 (35.7%), 331 (19.7%), and 30 (1.8%), respectively. Eyes in the ≥+2.00 and <+4.00 D initial *SE* category were predominantly stable in refraction and those in the two higher initial *SE* categories predominantly demonstrated mildly myopic shift. Approximately 52.2% (533/1022) of eyes in the ≥+2.00 and <+4.00 D category demonstrated longitudinal refraction stability. The percentages of eyes in the ≥+4.00 and <+6.00 and ≥+6.00 D categories were 33.4% (103/308) and 24.1% (85/353), respectively. Regarding initial J_0, percentage of eyes demonstrating refraction stability was 85.7% (6/7) in the ≤−0.50 D category, 32.1% (162/505) in the >−0.50 and <+0.50 D category, and 47.2% (553/1171) in the ≥+0.50 D category.

DISCUSSION

Data in our study give a picture of how *SE* refraction changes with age among Chinese schoolchildren with moderate to high hyperopia. In the study, a wide range of initial hyperopic refractive errors was examined, with a considerable sample size and adequate periods of follow-up. Rates of change in *SE* and distributions of patterns of refraction development were reported by participant initial refractions. The effects of age and sex on hyperopic refractive error evolution were determined.

Mean rate of change in *SE* in our sample of schoolchildren with initial *SE* ≥+2.00 and <+4.00 D was −0.30 D/year and that among children with initial *SE* ≥+4.00 and <+6.00 D and ≥+6.00 D was −0.38 and −0.45 D/year, respectively. In the Sydney Myopia Study, the 5-year mean change in *SE* was −0.87 D among children with baseline age of 6 years and *SE* ≥+2.00 and <+3.50 D, and −0.57 D among those with baseline *SE* ≥+3.50 D (Ilango M, et al. *IOVS* 2018;59:ARVO E-Abstract 3376). Although the figures of the two studies may not be exactly comparable, it seems likely that children in the Sydney Myopia Study underwent a much slower reduction in hyperopia compared to our Chinese hyperopic sample. It

−0.04 and $P < 0.001$; log likelihood and P value of the model were −5204.5 and < 0.0001, respectively). The associations of initial J_0 and J_{45} with the rate of change in *SE* were of borderline significance (for initial J_0, both $\beta = 0.005$, $P = 0.078$ and 0.045 in all and persistently nonmyopic children, respectively; for initial J_{45}, $\beta = 0.013$ and 0.009, $P = 0.021$ and 0.072 in all and persistently nonmyopic children, respectively).

A **Initial J0 <= -0.50 D**

SE = 2.54 -0.05 * age

B **Initial J0 >-0.50 and <+0.50 D**

SE = 7.70 -0.41 * age

C **Initial J0 >= +0.50 D**

SE = 5.72 -0.33 * age

D **Initial J45 <= -0.50 D**

SE = 6.70 -0.38 * age

E **Initial J45 >-0.50 and <+0.50 D**

SE = 6.35 -0.35 * age

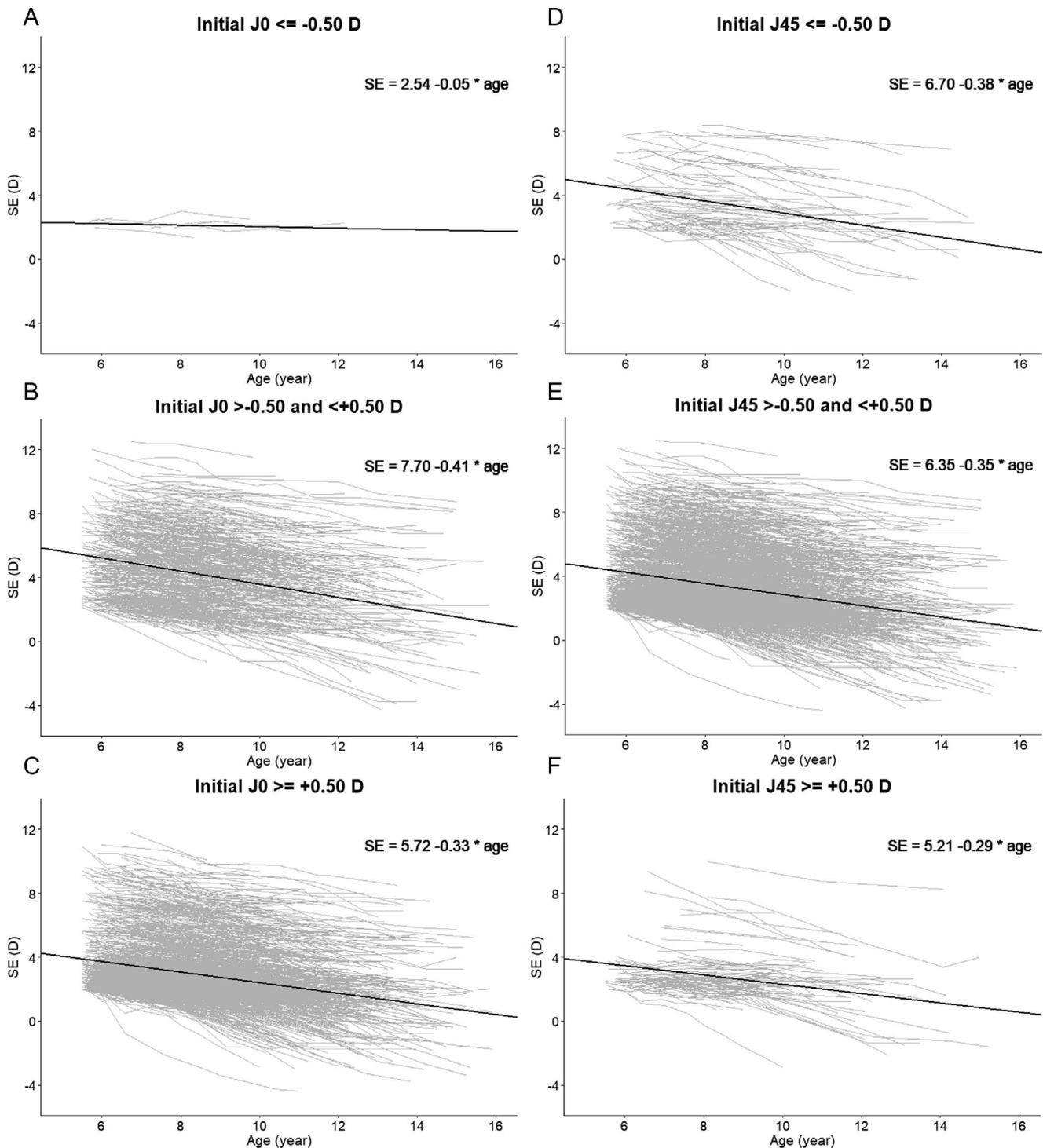**F** **Initial J45 >= +0.50 D**

SE = 5.21 -0.29 * age

FIGURE 4. Individual refraction evolutions and estimated linear regression lines of children with initial J_0 of ≤-0.50 D (**A**), >-0.50 and $<+0.50$ D (**B**), and $\geq+0.50$ D (**C**); and initial J_{45} of ≤-0.50 D (**D**), >-0.50 and $<+0.50$ D (**E**), and $\geq+0.50$ D (**F**).

should be acknowledged our data were obtained from clinical settings and the potential of bias could not be excluded. Data from the Refractive Error Study in Children (RESC) series demonstrate divergent patterns of refraction development among schoolchildren with different ethnicities and at different study sites.[16] Regarding hyperopia (*SE* refractive error $\geq+2.00$ D), specifically, there were substantial differences in the prevalence in young age groups among study sites; while by the age of 15, the prevalence cleared to insignificant levels

at most sites.[16] These data suggest that considerable variation in refraction development exists among hyperopic children of different ethnic origins and cultural settings.

In our sample of hyperopic children with a median initial age of 6.4 years and a median age at the final visit of 10.1 years, age and sex had small statistically significant, but clinically insignificant effects on the rate of change in *SE*. It seems that during this early period of school age, the pace of reduction in hyperopic refractive error is relatively constant across time and
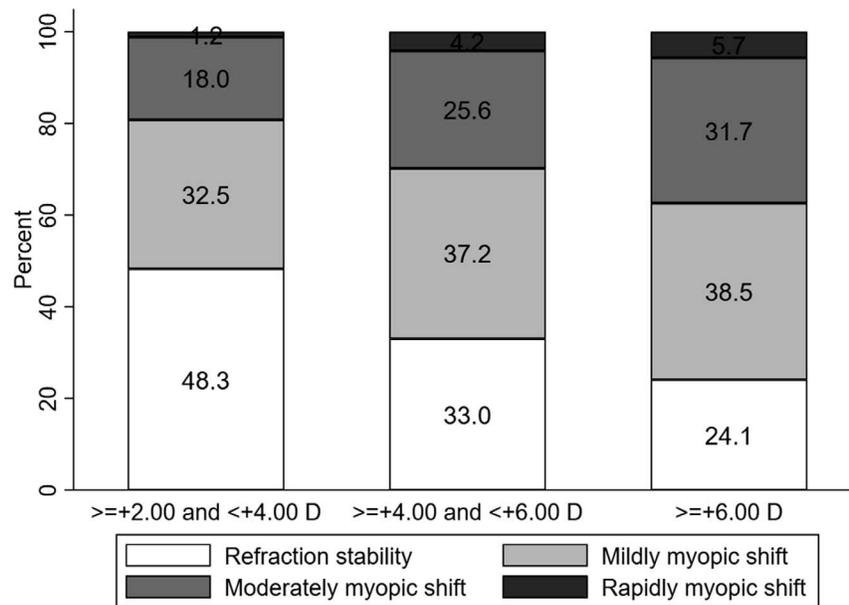
FIGURE 5. Bar graph showing distributions of the patterns of refraction development by initial *SE* refractive errors. Refraction stability, rate of change in *SE* less than ±0.25 D/year; Mildly myopic shift, rate of change in *SE* >-0.50 and ≤-0.25 D/year; Moderately myopic shift, rate of change in *SE* >-1.00 and ≤-0.50 D/year; Rapidly myopic shift, rate of change in *SE* ≤-1.00 D/year.

would not present great variation between boys and girls. However, limited to the relatively short follow-up of our study, full characterization of the evolution of hyperopia must be explored by further studies with longer follow-up extending into adolescence and early adulthood.

In our study, schoolchildren presenting greater initial hyperopia demonstrated faster rates of reduction in hyperopic *SE*. During the first year or two of human life, the rate of hyperopia reduction also positively relates to the initial level of hyperopia.[30,31] The exact mechanisms underlying the associations are not yet illuminated. It is likely that the human eyes can respond to some features related to refractive errors and converge toward a low hyperopic value over early life and the school age. "Regression to the mean" could be a contributor to the phenomenon of greater reduction in hyperopic *SE* among children with initial greater hyperopia. When analyzed by the duration of follow-up, the estimated amount of regression to the mean of this dataset (calculated as [1 − correlation between individual initial *SE* and *SE* at the last follow-up visit] × 100%) ranged from 4% to 24%.

While the longitudinal data suggested a reduction of hyperopia over time and greater reductions among eyes with higher levels of hyperopic *SE*, it must be noted that at the initial visit, children at older ages demonstrated greater hyperopic refractive errors (Table 1). It could be possible that higher levels of hyperopia create clinical symptoms more often among older children, making them appear at older ages in the clinic even as hyperopia becomes lower on an individual basis over time.

It is worth noting that, although the predominant pattern of refraction development differed among children with various initial hyperopic refractions, considerable percentages of eyes demonstrated refraction stability in all initial *SE* categories. It is suggested that the presence of significant hyperopia at age 6 years results from a failure of effective emmetropization during early life: having an initial hyperopia too great to be corrected and/or being very slow in longitudinal refraction change.[32] Little change in refraction has been observed in some highly hyperopic infants in previous longitudinal studies.[31,33,34] We speculated that among our study participants, at least some of

those who demonstrated refraction stability have persistent deficiencies in refraction change from birth through to their school age.

Our study is limited to its retrospective and hospital-based nature. However, it is not easy to obtain adequate numbers of highly hyperopic children using a prospective and population-based design. Compared to hyperopic children identified in the control group of the school-based Guangzhou Outdoor Activity Longitudinal study[35] (GOALs; $n = 97$; baseline age, 6.6 ± 0.4 years; 43 [44.3%] boys; and baseline *SE*, +2.42 ± 0.43 D [range, +2.00 to +3.63 D]), the mean rate of change in *SE* in children of our clinical sample with comparable initial refractive errors ($\geq$+2.00 and <+4.00 D initial *SE* group) was significantly slower (0.30 ± 0.25 vs. 0.39 ± 0.27, $P = 0.0005$, *t*-test). There was a probability that children with persistent hyperopia were more inclined to revisit the clinic and those with emmetropization might have missed their follow-up visits, leading to an underestimation of the rate of hyperopia reduction in this study. Optical correction can have an important impact on the growth of hyperopic eyes. However, we failed to collect and record children's compliance with spectacle prescription and the effect of optical correction remains uninvestigated. Ocular biometric data were not available. Thus, the precise mechanisms coordinating the optical and structural development of the eye cannot be completely understood. As a general limitation, the study results may not necessarily generalize to all hyperopic schoolchildren. There may be variations, depending on the sample ethnicity and cultural setting.

In conclusion, our study reported longitudinal changes in *SE* among Chinese schoolchildren with moderate to high hyperopia. On average, a reduction in the hyperopic refractive error was observed. Age and sex did not have clinically significant impacts on the rate of hyperopia reduction. Children with greater initial hyperopic refractive errors demonstrated faster rates of hyperopia reduction. Considerable percentage of eyes, even among children with high hyperopia, demonstrated longitudinal refraction stability. Further studies are warranted to examine the potential discrepancies among children of different ethnicities and cultural settings, to

determine the impact of optical correction on the refraction evolution, as well as to illuminate the longitudinal changes in ocular biometric parameters.

Acknowledgments

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