· Investigation ·

Progression of myopia among school-aged children in Guangzhou, China

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Abstract
● **AIM:** To investigate the prevalence and characteristics of myopia in school-aged students and effects of environmental and genetic factors on the progression of myopia.

● **METHODS:** A total of 2422 students aged between 5 and 18y from nine schools in Baiyun District of Guangzhou, China were sampled using a stratified sampling method in 2020. Among them, 1066 students participated in the follow-up survey the following year. Data were obtained based on ocular examinations and a questionnaire survey conducted during two visits. Factors potentially influencing the progression of myopia were analyzed.

● **RESULTS:** During the year assessed in this study, the percentage of students with myopia increased from 58.4% to 64.8% (P=0.002). Spherical equivalent (SE) progressed from -1.44±1.91 diopters (D) at baseline to -1.66±1.10 D (P=0.005). A generalized estimating equation (GEE) model revealed that age [adjusted odds ratio (aOR)=1.298, P<0.001], residential students (aOR=2.428, P=0.018), parental myopia (one myopic parent: aOR=1.553, both parents myopic: aOR=2.609, P<0.001), frequent reading of books or viewing of screens in direct sunlight (aOR=3.502, P=0.023), using only overhead lighting for reading and writing at night (aOR=1.633, P=0.011), parental restrictions on exercise time (aOR=2.286, P=0.012), and having less than 2h of outdoor exercise per day during the past week (aOR=1.584, P=0.019) were all identified as independent risk factors for progression of myopia.

● **CONCLUSION:** Our findings in this study indicate that age, residential students, parental myopia, indoor lighting environment, and physical activity have significant effects on the progression of myopia, providing evidence for further in-depth mechanistic interpretation and efficient intervention strategies for school-age children in this area.

● **KEYWORDS:** school-age children; prevalence; progression of myopia
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INTRODUCTION

Myopia, defined as a spherical equivalent (SE)≤-0.5 diopters (D), is typically associated with an excessive elongation of the eyeball, causing the image of distant objects to fall in front of the retina when the eyes are at rest, resulting in blurred distance vision[1]. Globally, myopia is becoming increasingly more prevalent, particularly in East Asia[2], and on the basis of data obtained for refractive examinations using cycloplegia, the prevalence of myopia in Asia (60%) is significantly higher than that in Europe (40%). This increase in the extent of myopia poses a significant public health challenge and it has been estimated that in 2015, the worldwide economic loss resulting from reduced productivity due to uncorrected myopia-related visual impairment amounted to $244 billion[3].
A considerable amount of data obtained in recent epidemiological studies has indicated that myopia generally develops during the early to middle stages of childhood[4-5], with non-cycloplegic measurements indicating extremely high rates of myopia among school-aged children in East Asia (73%)[6]. In addition to the occurrence of myopia, its progression has also attracted increasing attention in recent years. The findings of a Meta-analysis, conducted by Donovan *et al*[7] in 2012 among the adolescents and children in urban areas using glasses to correct myopia, revealed that the rate of myopia progression in the European population was -0.55 D per year, which compared with the -0.82 D per year progression in Asia, and this difference was found to become

more pronounced with an increase in the number follow-up years. Scholars in Hong Kong, China, have reported a rate of myopia progression of -0.63 D per year[8], and it has been estimated that myopia may develop at the age of 5 to 6y and progress to -5 to -6 D at the ages of 11 to 13y[9]. Furthermore, the age at myopia onset and the duration of progression have been identified as the most important prognostic factors for the development of acute myopia in later childhood[10]. Children with early onset myopia tend to have a longer course of impaired vision, a more rapid progression of myopia, and a higher risk of developing acute myopia and experiencing myopic macular degeneration[11].

Although the precise mechanisms underlying the development of myopia have yet to be fully elucidated, current evidence suggests that it is influenced by a combination of genetic and environmental risk factors[12-13]. Commonly acknowledged risk factors for myopia include ethnicity, higher levels of education, limited outdoor activity, excessive near work, and parental myopia[1,14].

Given the high incidence of myopia in Asia, analysis of the risk factors associated with the onset and development of this disorder in children and adolescents in the Asian region is essential for the development of effective interventions. In this regard, whereas some studies have sought to assess the progression of myopia, much of the research has focused on clinical experimental studies evaluating intervention measures for controlling myopia in primary and secondary school students. In this study, we conducted a 2-year longitudinal observational assessment of the growth trajectory of myopia among school-aged children in the Baiyun District of Guangzhou, China, from 2020 to 2021. Additionally, we sought to obtain evidence for an in-depth mechanistic interpretation of the condition among school-age children in this area and for development of efficient intervention strategies.

PARTICIPANTS AND METHODS

Ethical Approval Informed consent was obtained from the participants and their parents (or legal guardians) at the time of data collection, and confidentiality was ensured. The study was approved by the Ethics Committee of the Guangzhou Center for Disease Control and Prevention (approval number: GZCDC-ECHR-2019P0044).

Study Cohort This was a population-based cross-sectional study, for the purposes of which, we used a stratified cluster sampling method to select students aged between 5 and 18y in the Baiyun District, including students from two kindergartens, two elementary schools (grades 1–6), two junior high schools (grades 1–3), two high schools (grades 1–3), and one vocational secondary school (grades 1–3). Students with other eye conditions, such as amblyopia, strabismus, ptosis, glaucoma, congenital cataracts, or severe systemic diseases, were excluded from the study. Baseline data were collected in September 2020, and follow-up examinations were performed in September 2021. Annual changes in visual acuity changes were traced longitudinally based on ocular examinations and questionnaire surveys.

Questionnaire The questionnaire used in this study was designed based on the requirements of the Investigation Plan for Myopia in Children and Adolescents issued by the Ministry of Education. To control for interview bias, experts conducted validation and reliability assessments of the questionnaire survey. The questionnaire consisted of 37 questions divided into eight sections, and was completed by children who were able read the questions, with assistance from at least one trained school doctor or research team investigator during the completion process. The questions covered various aspects, including basic student information, visual behavior both at school and outside school, reading and writing posture, electronic screen usage time, near-work habits, outdoor activities, sleep conditions, myopia examination, and correction.

Ocular Examination Participants underwent standardized eye examinations, including measurements of uncorrected visual acuity and non-cycloplegic refractivity. All students were assessed for distance visual acuity without spectacles using a logarithmic visual acuity chart (GB/T 11533–2011) at a distance of 5 m. The chart has 14 rows of tumbling E markers of varying sizes, and the test required the subjects to cover one eye and indicate the opening of the marker (first left, then right). The refractive errors were measured using an automated refractometer (KR-8800; Topcon, Tokyo, Japan) under non-paralyzed conditions, with the four parameters spherical power, cylindrical power, axis, and SE, being assessed. For each eye, average values were obtained based on three repeated measurements. All examinations were conducted by a licensed ophthalmologist with clinical experience, an optometrist with relevant qualifications in optometry, and a certified nurse.

Definitions The SE criterion was used to determine the refractive errors of the SE, calculated based on the spherical power and the cylindrical power, where SE=spherical power+1/2×cylindrical power. Hyperopia was defined as $SE>+0.50$ D, emmetropia as $-0.50<SE\leq+0.50$ D, and myopia as $SE\leq-0.50$ D[15]. Subdivision of the degree of myopia of $-3.00<SE\leq-0.50$ D, $-6.00<SE\leq-3.00$ D, and ≤-6.00 D were classified as mild, moderate, and high myopia, respectively. Among participants for whom we obtained data regarding the progression of diopters, the first visit was defined as the baseline survey record, the subsequent visit was defined as the follow-up visit, and the final visit was defined as the endpoint visit record. Baseline age, diopters, astigmatism, and refractive status were defined as the baseline age, diopters, astigmatism,

Table 1 The demographic characteristics of myopic and emmetropic subjects at baseline

Characteristics	Total (*n*=2422)	Myopia (*n*=1584, 65.4%)				Emmetropia (*n*=838, 34.6%)	P^a	P^b
		Total myopia (*n*=1584)	Mild myopia (*n*=958)	Moderate myopia (*n*=503)	High myopia (*n*=123)			
Age, mean±SD (y)	12.5±3.8	13.9±3.2	13.1±3.3	14.9±2.5	15.9±1.7	9.9±3.6	<0.001	<0.001
Sex, *n* (%)							<0.001	0.078
Boys	1259 (52.0)	759 (60.3)	481 (63.4)	223 (29.4)	55 (7.2)	500 (39.7)		
Girls	1163 (48.0)	825 (70.9)	477 (57.8)	280 (33.9)	68 (8.2)	338 (29.1)		
Grade, *n* (%)							<0.001	<0.001
Kindergarten	162 (6.7)	28 (17.3)	26 (92.9)	2 (7.1)	0	134 (82.7)		
Primary school (grade 1 to 3)	395 (16.3)	119 (30.1)	111 (93.3)	8 (6.7)	0	276 (69.9)		
Primary school (grade 4 to 6)	514 (21.2)	296 (57.6)	226 (76.4)	67 (22.6)	3 (1.0)	218 (42.4)		
Junior high school	546 (22.5)	448 (82.1)	269 (60.0)	146 (32.6)	33 (7.4)	98 (17.9)		
Vocational high school	259 (10.7)	200 (77.2)	107 (53.5)	75 (37.5)	18 (9.0)	59 (22.8)		
High school	546 (22.5)	493 (90.3)	219 (44.4)	205 (41.6)	69 (14.0)	53 (9.7)		
Mode of study, *n* (%)							<0.001	<0.001
Day student	1443 (59.8)	743 (51.5)	536 (72.1)	179 (24.1)	28 (3.8)	700 (48.5)		
Residential student	969 (40.2)	833 (86.0)	418 (50.2)	321 (38.5)	94 (11.3)	136 (14.0)		
Number of myopic parents, *n* (%)							0.005	0.204
0	957 (51.7)	710 (74.2)	423 (59.6)	234 (33.0)	53 (7.5)	247 (25.8)		
1	626 (25.8)	497 (79.4)	275 (55.3)	178 (35.8)	44 (8.9)	129 (20.6)		
2	267 (11.0)	220 (82.4)	118 (53.6)	76 (34.5)	26 (11.9)	47 (17.6)		

[a]Two-sided Chi-square test was used to compare the frequency distribution of categorical variables, and the Mann-Whitney *U* test was used to compare the mean values of continuous variables between subjects with myopia and emmetropia. [b]Two-sided Chi-square test was used to compare the frequency distribution, and the Kruskal-Wallis *H* test was used to compare the mean values of the continuous variables among subjects with mild, moderate, and high myopia. SD: Standard deviation.

and refractive status, respectively[16]. The progression of myopia was defined as the difference between SE at baseline and at the 1-year follow up. Given that the SE of the left and right eyes were highly correlated (Pearson correlation coefficient=0.87, $P<0.001$), for all analyses we used only the data obtained for the right eye.

Statistical Analysis A database was established using EpiData 3.1, general statistical analysis was carried out using SPSS software (version 25.0; SPSS Inc., Chicago, IL, USA), and graphical illustrations were prepared using GraphPad Prism 8.0.1 (GraphPad Software, San Diego, CA, USA). Data pertaining to demographic and ocular characteristic were expressed as the mean±standard deviation (SD) or percentage (%). The Chi-square test was used to compare categorical variables between groups, and continuous variables with non-normal distribution, such as SE and axis position (AP), were compared using the Mann-Whitney *U*-test and Kruskal-Wallis *H* test. In addition, the rank sum test of paired samples and a paired Chi-square test were used to analyze changes in ocular examination parameters and categorical variables, respectively. A generalized estimating equation (GEE) model was used to evaluate the risk factors associated with myopic progression, and values were calculated for the crude odds ratios (cORs), adjusted odds ratios (aORs), and 95% confidence interval (95%CI). A two-sided *P* value of 0.05 or less was considered to be statistically significant.

RESULTS

Demographic Information at Baseline and Myopia Prevalence A total of 2422 subjects were enrolled in the study, among whom there were 1259 (52.0%) schoolboys and 1163 (48.0%) schoolgirls, for whom the mean of spherical power, cylindrical power, and SE were -1.52±2.01 D, -0.61±0.62 D, and -1.82±2.10 D, respectively. AP was 98.2±74.8°, and unaided vision and vision with glasses were 4.6±0.4 and 4.7±0.4, respectively. On the basis of the results of an ocular examination of SE in the right eye, the subjects were divided into myopia and emmetropia groups. The myopia group was further divided into mild, moderate, and high myopia groups. At baseline, there were 1584 subjects defined as myopic, representing 65.4% of the assessed population, among whom, the proportions with mild, moderate, and high myopia were 39.6% (*n*=958), 20.8% (*n*=503), and 5.1% (*n*=123), respectively (Table 1).

As shown in Table 1, there were statistically significant differences in the distribution of age, grade, and mode of study between the myopia and emmetropia groups and among different degrees of myopia ($P<0.05$). In addition, with respect to sex and parental myopia, we detected statistically significant differences only between the myopia and emmetropia groups (P<0.05). Participants with myopia were older (13.9±3.2y) compared to those without myopia (9.9±3.6y), and with the degree of myopia increasing with an increase in age (mild myopia: 13.1±3.3y; moderate myopia: 14.9±2.5y; high myopia: 15.9±1.7y). Myopia occurs more frequently in girls (825/1163, 70.9%) compared with schoolboys (759/1259, 60.3%). High school students and residential students (833/969, 86.0%) had a higher myopia rate (493/546, 90.3%). Students whose both parents were myopic (220/267, 82.4%) have a higher incidence of myopia than those whose either parent is myopic (497/626, 79.4%) or whose parents are not myopic (710/957, 74.2%).

Analysis revealed a correlation between age and the prevalence of myopia, χ^2=94.689 (P<0.001), with Pearson and Spearman rank correlation coefficients of 0.811 (P<0.001) and 0.644 (P<0.001), respectively, indicating a strong positive correlation between age and the prevalence of myopia, the incidence of which was found to show a significant increase with age.

The overall prevalence of myopia by age was shown in Figure 1. The proportions of myopic children among subjects aged ≤5 and 6y old were 16.7% and 15.7%, respectively. However, the proportion of students with myopia began to increase sharply at 7y (29.7%), and continued to gain in prevalence with increasing age, with proportions of 37.3%, 33.5%, 54.7%, 55.0%, and 73.4% being recorded among children of 8, 9, 10, 11, and 12 years of age, respectively. Among children aged 13y and older, the rate of increase tended to slow, although among students aged 18 and above, the proportion affected reached 88.6%. The rate of which myopia progressed tended to be linear over time, with the most rapid phase of progression of mild myopia being observed in children aged 6 to 7, 9 to 10, and 11 to 12y at baseline; however, there was a brief decline at 15 to 16 years of age. Moderate myopia begins to show a significant progression among children aged 8 to 9y, and having declined briefly at age 15 to 16y, thereafter continued to rise, whereas the incidence of high myopia began to increase significantly from the age of 12 to 14y and thereafter progress slowly after a brief decline at age 14 to 15, reaching a proportion of 12.4% among subjects of 18 years of age. Our analysis of ocular examination results among those with different grades revealed that the spherical power of the subjects declined with an increase in grade level, and that the cylindrical power continued to decline, reaching a stable level after junior high school. Accordingly, there was an overall decline in the SE of the participants with an increase in grade level. The directions of change in uncorrected visual acuity and optometric visual acuity were essentially the same at baseline, with a significant decline in junior high and high school, and AP was found to gradually lengthen before junior high school and shortened during junior high school.

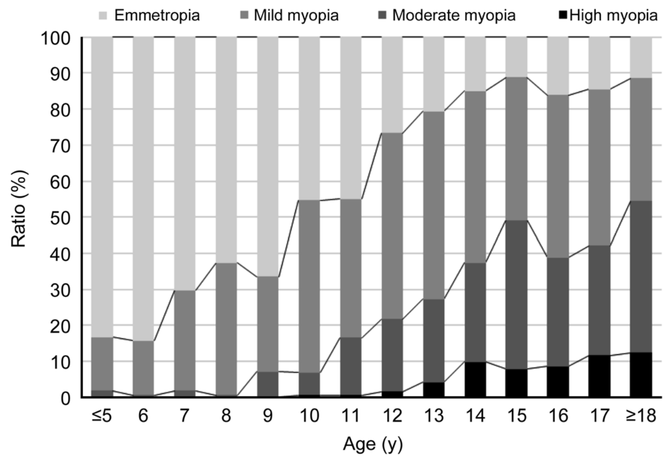

Figure 1 Overall prevalence of myopia by age at baseline among those with emmetropia, mild myopia, moderate myopia, and high myopia.

Myopia Progression Of the 2422 students enrolled at baseline and monitored after 1y, 1066 were included for follow-up (excluding students who entered higher school, transferred, or did not take the questionnaire). When assessed at the 1-year follow up, the proportion of students with myopia had increased from 58.4% to 64.8% (P<0.05). Among these individuals, 24 (2.3%) had progressed from no myopia to mild myopia, 42 (3.9%) from mild to moderate myopia, and two (0.2%) to high myopia (P<0.05), and during this period, the wearing of visual aids (including spectacles, contact lenses, and night vision glasses) increased from 28.4% to 31.2% (P<0.05). Furthermore, from baseline the spherical power (mean±SD) had progressed from -1.16±1.84 to -1.37±1.92 D (P<0.05), the SE (mean±SD) from -1.44±1.91 to -1.66±1.10 D (P<0.05), and the unaided vision from 4.7±0.4 to 4.6±0.4 (P<0.05). There were no significant differences between the 2y with respect to the changes in cylindrical power, AP, or vision with glasses (Table 2). After 1y, there were 44 (7.6%) and 24 (4.9%) new cases of myopia among boys and girls, respectively, with corresponding changes in SE of -0.94±1.75 and -1.36±1.98, with the difference between the two groups being non-significant. Elementary school students were found to be more prone to developing myopia, with 27 cases (8.1%) in grades 1–3 and 27 cases (9.3%) in grades 4–6. Progression in SE was observed at all stages of schooling, although we detected no significant differences among the assessed groups. Changes in the assessed ocular parameters according to sex and grade were shown in Table 3.

Analysis of the Factors Influencing Myopia Progression A GEE model was used to assess factors associated with the progression of myopia over a 1-year period, with analysis being performed using univariate and multivariate logistic regression, the results of which were summarized in Table 4. In the GEE model, the incidence of myopia was regarded as the dependent

Table 2 The ocular characteristics of right eyes at baseline and follow-up

Characteristics	Baseline (*n*=1066)	Follow-up (*n*=1066)	Change	χ^2/t	P^a
Myopia, *n* (%)	623 (58.4)	691 (64.8)	68 (6.4)	9.172	0.002
Level of myopia, *n* (%)				11.211	0.011
Mild	427 (40.1)	451 (42.3)	24 (2.3)		
Moderate	161 (15.1)	203 (19.0)	42 (3.9)		
High	35 (3.3)	37 (3.5)	2 (0.2)		
Glasses type, *n* (%)				7.872	0.049
Frame glasses	298 (28.0)	319 (29.9)	21 (2.0)		
Contact lens	1 (0.1)	0	-1		
Overnight orthokeratology lens	4 (0.4)	14 (1.3)	10 (0.9)		
No glasses	763 (71.6)	733 (68.8)	-30 (-2.8)		
Spherical power, mean±SD (D)	-1.16±1.84	-1.37±1.92		-2.687	0.007
Cylindrical power, mean±SD (D)	-0.57±0.58	-0.59±0.60	-0.33±0.29	-0.770	0.441
SE, mean±SD (D)	-1.44±1.91	-1.66±1.10	-0.22±0.76	-2.808	0.005
AP, mean±SD (°)	102.0±75.2	101.1±74.8	-0.91±79.74	-0.994	0.320
Unaided vision, mean±SD	4.7±0.4	4.6±0.4	0.07±0.18	-3.863	<0.001

[a]The rank sum test of paired samples and paired Chi-square test were used to analyze changes in ophthalmic examination parameters. SD: Standard deviation; D: Diopters; SE: Spherical equivalent; AP: Axis position.

Table 3 Changes in SE and myopia prevalence stratified by sex and grades

Characteristics	Myopia, *n* (%)				SE (mean±SD, D)			
	Baseline	Follow-up	Changes	P^b	Baseline	Follow-up	Changes	P^b
Sex								
Boys	305 (52.9)	349 (60.5)	44 (7.6)	<0.001	-1.26±1.82	-1.48±1.89	-0.94±1.75	<0.001
Girls	318 (65.0)	342 (69.9)	24 (4.9)	0.007	-1.65±1.99	-1.88±2.10	-1.36±1.98	<0.001
P^a			0.253				0.645	
Grades								
Primary school (grade 1 to 3)	111 (33.2)	138 (41.3)	27 (8.1)	0.003	-0.37±0.83	-0.61±1.14	-0.29±1.16	<0.001
Primary school (grade 4 to 6)	149 (51.0)	176 (60.3)	27 (9.3)	<0.001	-0.98±1.35	-1.23±1.62	-0.72±1.53	<0.001
Junior high school	156 (85.2)	157 (85.8)	1 (0.6)	1.000	-2.44±2.07	-2.63±2.03	-1.94±1.96	0.005
Vocational high school	98 (71.0)	110 (79.7)	12 (8.7)	1.000	-2.27±2.34	-2.49±2.35	-1.78±2.19	<0.001
High school	109 (91.6)	110 (92.4)	1 (0.8)	0.012	-3.08±2.16	-3.23±2.21	-2.47±2.17	0.002
P^a			<0.001				0.346	

[a]Statistical significance was assessed using the Chi-square test, variance analysis, and the Kruskal-Wallis *H* test. [b]Within-group comparison between baseline and follow-up using paired Chi-square and paired *t*-tests. SD: Standard deviation; D: Diopters; SE: Spherical equivalent.

variable, and each dimension of the behavioural characteristics was treated as an independent variable, among which, age, parental myopia, frequent reading of books or viewing of electronic screens in direct sunlight, use of ceiling lights only for reading and writing at home after dark, parents limiting the time of exercise, and less than 2h of outdoor exercise per day during in the past week. We found that the likelihood of developing myopia increased with age (aOR=1.298, *P*<0.001), with residential students identified as being at a higher risk of myopia progression than day students (aOR=2.428, *P*=0.018). Furthermore, the risk of myopia progressing increased among children for whom one parent was myopic (aOR=1.553, *P*=0.047), and was higher still when both parents were myopic (aOR=2.609, *P*<0.001). Additionally, students who frequently read in direct sunlight had a higher risk of developing myopia than those who never read in direct sunlight (aOR=3.502, *P*=0.023). Moreover, students who read and wrote using only ceiling lights for illumination after dark were found to be at a higher risk of developing myopia than those who used both table lamps and ceiling lights (aOR=1.633, *P*=0.011). Students whose parents often restricted their exercise time to prioritize study time were identified as having a higher risk of developing myopia than those who were not subjected to such restrictions (aOR=2.286, *P*=0.012), and, similarly, those who daily spent two or fewer hours participating in outdoor activities in the previous week were found to have a higher risk of developing myopia than those who spent 3h or more engaged in such activities (aOR=1.584, *P*=0.019).

Table 4 Regression analysis of factors associated with the progression of myopia within 1y among primary and middle school students

Parameters	Incidence of myopia (*n*=1066)			
	Univariate analysis		Multivariate analysis	
	cOR (95%CI)	*P*	aOR (95%CI)	*P*
Age	1.397 (1.292, 1.51)	<0.001	1.298 (1.128, 1.493)	<0.001
Sex				
Girls	1.421 (1.017, 1.987)	0.040	1.262 (0.861, 1.851)	0.232
Boys	Reference	-	Reference	-
Mode of study				
Residential student	5.926 (3.72, 9.44)	<0.001	2.428 (1.161, 5.077)	0.018
Day student		Reference		Reference
Parental myopia				
Both parents are myopic	1.747 (1.101, 2.775)	0.018	2.609 (1.539, 4.423)	<0.001
Only father or mother is myopic	1.205 (0.835, 1.739)	0.319	1.553 (1.006, 2.398)	0.047
Neither parent is myopic	Reference	-	Reference	-
Frequency of reading books or viewing electronic screens in direct sunlight				
Always	1.819 (0.503, 6.573)	0.362	2.507 (0.605, 10.392)	0.205
Frequently	3.571 (1.382, 9.226)	0.009	3.502 (1.19, 10.305)	0.023
Occasionally	1.827 (1.336, 2.5)	<0.001	1.182 (0.785, 1.78)	0.422
Never	Reference	-	Reference	-
Lights for reading and writing at home after dark				
Only ceiling lights	1.244 (0.898, 1.722)	0.189	1.633 (1.117, 2.386)	0.011
Only table lamps	1.004 (0.627, 1.609)	0.986	1.478 (0.849, 2.572)	0.167
Both ceiling lights and table lamps	Reference	-	Reference	-
Whether parents limit the time of exercise				
Often	2.361 (1.378, 4.046)	0.002	2.286 (1.198, 4.362)	0.012
Occasionally	1.564 (0.9, 2.717)	0.013	1.794 (0.924, 3.481)	0.084
Never	Reference	-	Reference	-
Time spent outdoors in the past week (h/d)				
≤2	1.561 (1.116, 2.183)	0.009	1.584 (1.08, 2.323)	0.019
2-3	1.527 (1.028, 2.267)	0.036	1.589 (0.984, 2.565)	0.058
≥3	Reference	-	Reference	-

cOR: Crude odds ratio; aOR: Adjusted odds ratio; CI: Confidence interval.

DISCUSSION

To date, a majority of the studies that have assessed the prevalence of myopia have tended to focus on the average prevalence of myopia in populations, and there has been comparatively little research examining the longitudinal changes among groups differentiated with respect to the severity of myopia. In this study, we assessed the distribution patterns of the prevalence of myopia among 2422 students at baseline, the trends in prevalence and SE progression among 1066 students from 2020 to 2021, and the factors influencing the progression of myopia.

Pattern of Myopia Development Among the study population, the baseline proportion of myopia in 2020 was 65.5%, which is higher than the 60.1% that has been estimated for Chinese Han children and adolescents aged 7 to 18 in 2019[17]. Within the study cohort, the overall prevalence of myopia increased by 6.4% over the course of 1y, with a mean annual progression of -0.22±0.76 D in SE, which was lower than the rates of progression ranging from -0.48 to -1.42 D per year reported in different clinical trials conducted in France, Singapore, and other regions of mainland China. The progression recorded in the present study was, however, comparable to the reported incidence of myopia among 5 to 15-year-old myopic children in Northern India (-0.27 D per year). We suspect that these differences among studies could be attributable to differences in the methods used to measure myopia, timeframes, age ranges, or geographical regions, and could also be associated with a greater emphasis in recent years on myopia screening and interventions in certain regions. Our findings in this study revealed a significant correlation between age and myopia in students, and on the basis of a stratification of individuals with different degrees of myopia, these findings provide evidence of a progression in the proportion of children with mild and moderate myopia towards a high myopic population. Compared with individuals with moderate myopia, we established that children with mild myopia tend to be significantly younger, with a prevalence of myopia of 14.8% among children aged ≤5y, indicating a trend towards early-onset myopia. Zhong *et al*[17] similarly pointed out a worrying trend in myopia among young Han Chinese children and adolescents. In addition, we found that the rate of myopia increased most rapidly with age among children in elementary school, and that the overall rate of progression began to slow during the years at middle school. The three significant jumps in prevalence in primary school observed at ages 6 to 7, 9 to 10, and 11 to 12y, roughly coincide with grades 1, 4, and 6, respectively. Jones-Jordan *et al*[5] estimated that Asian American children had a progression of -1.93 D with onset at age 7 compared with -1.43 D at age 10, and that there was an annual 0.07 D decline in the rate of progression for each year of increasing age of onset. Furthermore, in a cohort study conducted in France, Tricard *et al*[18] established that myopia tends to progress more rapidly in children aged 7 to 9 and 10 to 12y. In a further study, Chua *et al*[11] found that the highest incidence of myopia in Singaporean children typically occurs among those between the ages of 8 and 10. These findings provided further evidence to indicate that the onset and progression of myopia tend to occur at specific age intervals.

It can be speculated that this pattern was partially attributable to differences in learning, as Chinese primary school students may experience academic pressure and an increased workload at an earlier stage, given the emphasis on passing entrance examinations. Interestingly, we observed that compared with primary school students, the progression of myopia tended to become less evident during high school years. Thus, despite the assumption that high school students use their eyes more frequently during the course of their studies or in the use of electronic devices, the progression to myopia among these students was not as pronounced as that observed among younger children, which might imply that the onset of myopia at a younger age is particularly harmful to vision[19].

Factors Influencing Myopia Progression Overall, our findings in this study were consistent with the those of previous studies that examined the influence of genetic and environmental factors, on the basis of which, we can draw the following conclusions.

We obtained persuasive evidence to indicate the significant role of genetic factors, as revealed by our finding that the risk of myopia progression increased when one parent was myopic (aOR=1.553) and was higher when both parents were myopic (aOR=2.609). Similarly, Saw *et al*[20] and Kurtz *et al*[21] found that the more myopic the parents, the higher was the incidence of myopia in their children.

Moreover, whereas the findings of previous studies have tended to indicate that sex may influence the progression of myopia, the outcome of our assessment of an association between sex and the progression of myopia failed to support this hypothesis. For example, whereas males have previously been shown to have a significantly higher hyperopic SE than females[22], we observed that in all assessed age groups, females generally had a more rapid 1-year progression of SE than males. However, when behavioural factors were incorporated into the GEE model, sex did not emerge as a significant predictor of near-sighted progression. On the basis of these findings, we infer that the observed differences in myopia progression between males and females are more likely to be associated with differences in behavioural patterns rather than gender per se. In this regard, it is plausible that girls spend a larger proportion of time studying and less time participating in outdoor activities, which could contribute to the observed differences in the progression of myopia.

Our findings also provided evidence for the beneficial effects of outdoor activities. Notably, during the COVID-19 pandemic, a range of lockdown measures limited outdoor activities for children and adolescents, resulting in a marked reduction in outdoor activities[23-24]. In the GEE model, accommodation, parental restrictions on exercise time, and less than 2h of outdoor activities per day during the previous week were included as independent risk factors for myopia. Although the findings of numerous previous studies have confirmed the beneficial effects of outdoor sunlight with respect to the development of myopia, as opposed to exercise *per se*, we identified an association between whether students lived on campus and exercise and outdoor activity times. Students living on campus may have less exercise time, including outdoor activity time, than day students. Indeed, the introduction of several public health policies have successfully contributed to reducing the overall incidence of myopia in students by encouraging them to engage in outdoor activities. For example, in an interventional trial involving 12 schools and 1903 first-grade children in Guangzhou, China, the intervention group was required to participate in 40min of outdoor classes daily. Three years later, the incidence of myopia was found to be significantly lower in this group than in a control group (30.4% *vs* 39.5%)[25]. In addition, in certain regions, education policies have stipulated an increase of at least 80min of outdoor time per day, resulting in a reduction in the incidence of myopia from 17% to 8%, and a corresponding reduction in the degree of myopia from refractive 0.38 to 0.25 D[26]. Furthermore, the findings of recent studies have indicated that artificial natural light in primary school classrooms can reduce the incidence of myopia over a 3-year period, which reflects the preventive effect of natural light on myopia[27]. To date, however, the association between outdoor activities and a lower incidence of myopia has yet to be conclusively established, possibly due to factors such as higher light intensity, changes in chromatic composition, differences in refractive topography, less near work, and reduced adaptation requirements[15,28].

Furthermore, the GEE model indicated that students who relied solely on ceiling lights for reading and writing after dark were 1.633 times more likely to experience progressive myopia within a year than those who used illumination from both ceiling lights and desk lamps. This finding highlights the significance of the indoor lighting conditions. In this regard, the findings of an interventional study conducted by Harrington and O'Dwyer[29] revealed that high degree of brightness in classrooms had a significant influence on the occurrence of myopia and reduced refractive error and axial growth. Consequently, opting to read and write in environments with inadequate lighting may contribute to visual discomfort. During the course of the COVID-19 pandemic, owing to factors such as the suspension of offline classes, students generally spent large amounts of time indoors, which may have been a factor influencing the progression of myopia observed in the present study.

However, despite our important findings, this study has certain limitations that should ideally be acknowledged when interpreting the results. Notably, there may have been errors in measuring refraction in the absence of ciliary paralysis. Although refractive testing without cycloplegia is less accurate than refractive testing with cycloplegia, screening and monitoring for myopia is more feasible in large cohorts. In addition, given that behavioural habits were assessed using questionnaires, although the reliability and validity of the questionnaire were expertly verified and acceptable, there remains a possibility of recall bias. Furthermore, the baseline data included those obtained for kindergarten and primary grade 1 to 3 students. However, given that only older students could independently complete the questionnaire, we initially introduced the questionnaire survey and myopia progression analysis at the level of the fourth grade of primary school, thereby resulting in a disparity in the respective sample sizes. In addition, on account of factors associated with graduation and the COVID-19 pandemic, a certain proportion of students were lost to follow-up, with only 1066 of the 2422 initially enrolled students being sufficiently followed up. Nevertheless, the data obtained for these individuals proved valuable for analysis. Finally, the study was conducted over a limited period of only a single year, which may have accounted for a non-significant relationship between certain factors associated with myopia-related behavior and changes in the proportion of myopia. In the future, we will continue to follow changes in myopic individuals over a longer period and complement this monitoring by conducting research on cycloplegia.

This study was based on a cohort survey of primary and secondary school students in China, the findings of which highlight the significant role of genetic factors in the development of myopia. However, when accounting for both genetic and behavioural factors, we discovered that there was no discernible difference between males and females with respect to the likelihood of near-sighted progression among students within a 1-year timeframe. Furthermore, we identified indoor and outdoor lighting environments as key factors influencing the progression of near-sightedness, thus providing a scientific basis for myopia intervention in school-age children in this area. Future research efforts should place greater emphasis on investigating the duration of outdoor activity and conducting comprehensive studies with larger sample sizes and longer follow-up periods to gain a more complete understanding of the associations among outdoor activity, lighting, and the progression of myopia.

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