Original Article

The associations of high academic performance with childhood ametropia prevalence and myopia development in China

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Background: To assess associations of high academic performance with ametropia prevalence and myopia development in Chinese schoolchildren.

Methods: This multicohort observational study was performed in Guangdong, China. We first performed a cross-sectional cohort analysis of students in grades 1 to 9 from Yangjiang to evaluate the relationship between academic performance and refractive status on a yearly basis. We also performed longitudinal analyses of students in Shenzhen to evaluate the trend of academic performance with refractive changes over a period of 33 months. All refractive statuses were measured using noncycloplegic autorefractors.

Results: A total of 32,360 children with or without myopia were recruited in this study (mean age 10.08 years, 18,360 males and 14,000 females). Cross-sectional cohort analyses in Yangjiang showed that the prevalence of hyperopia was associated with lower academic scores in grade one, the year students entered primary school (β=−0.04, P=0.01), whereas the prevalence of myopia was associated with higher academic scores in grade six and grade eight, the years in which students were about to take entrance examinations for junior high school or senior high school (β=0.020, P=0.038; β=0.041, P=0.002). Longitudinal analysis showed that in Shenzhen, faster myopia development was associated with better scores in all grades even after adjustments for BMI, outdoor activity time, screen time, reading time, and parental myopia (grade two at baseline: β=0.026, P<0.001; grade three at baseline: β=0.036, P=0.001; grade four at baseline: β=0.014, P<0.001; grade five at baseline: β=0.039, P<0.001; grade six at baseline: β=0.04, P<0.001).

Conclusions: Refractive errors correlated significantly with academic performance among schoolchildren in China. Children with high academic performance were more likely to have faster myopia development.

Keywords: Refractive error; hyperopia; myopia; academic performance; cohort study

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Introduction

The prevalence of refractive error is associated with education. A recent study has indicated that an individual's years of education correlated positively with the development of myopia (1). In addition, learning intensity such as continuous reading by an individual is associated with the development of myopia (2). Overall, the studies of associations between education related factors and refractive errors among schoolchildren have significant implications for public health.

The overall prevalence of refractive error is much higher in East Asians than in other ethnic populations (3). In China, an exam-driven educational system in which higher-performing students are selected based on their level of academic performance has been implemented for over a thousand years (4). Chinese students tend to work hard for long hours for school-related learning (5). A recent investigation conducted from 2015 to 2017 with 572,314 Chinese students reported that Chinese students spend large amount of time on homework (6). On average, 50.2% and 45.5% of students spend more than 30 minutes on math and Chinese homework, respectively. A total of 43.8% and 37.4% fourth graders attend after-school math and Chinese classes, respectively (6). However, a correlation between refractive errors and academic performance in China has not been established.

Studies conducted in Singapore, India, Tunisia, America, and the UK have reported an association between refractive error and academic achievement (7-12). However, most studies analyzed individuals in a specific grade or at a specific age (7,12) and only recruited a small study population (7,8,11,12). Studies conducted in Surat and Tunisia analyzed 3,002 students but only focused on individuals of a specific sex (9) or a specific refractive status (10). As the prevalence of refractive errors in the education system varies by region and ethnic group (13), it is critical to conduct a comprehensive study in Chinese school-aged students to investigate the relationship between refractive errors and academic performance. Moreover, no longitudinal follow-up analyses have clarified the association between academic performance and myopia development worldwide. Here, we investigate the associations of high academic performance with childhood ametropia prevalence and myopia development in China which will contribute to the development of strategies for academic improvement and visual protection. We present the following article in accordance with the STROBE reporting checklist (available at http://dx.doi.org/10.21037/atm-20-8069).

Methods

Study design

This multicohort study was conducted over a 3-year period beginning in 2016–2017 (National clinical trial, NCT04338880). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Institutional Review Board of Zhongshan Ophthalmic Center (No. 2010175) and informed consent was taken from all the patients.

The study examined two closed cohorts of students in Guangdong, China. A cohort consisted of students in grade one to grade nine (aged 6–15) in 2016–2017 from Yangjiang to evaluate the relationship between academic performance and refractive status on a yearly basis in a cross-sectional cohort design. Meanwhile, a cohort enrolled students from Shenzhen in grade two to grade six (aged 7–12) in 2016–2017 to evaluate the trend of academic performance with refractive changes over a period of 33 months or years. Data from the Shenzhen cohort were collected during annual health monitoring examinations. All of the participated students were from urban locations.

Measures and outcome

Interview
The recruited students underwent a brief interview on their ocular health. Students were excluded from this study if they had a history of wearing rigid contact lenses or if they had a history of medical treatment or a disease that might affect their vision or vision development, such as amblyopia and diabetes.

Slit-lamp examination
The students underwent comprehensive, standardized slit-lamp examinations in a dimly lit indoor area using BIO-SLIPSes (New vision, China). Students were excluded from this study if they had cataracts, keratitis, strabismus or other diseases that could cause poor vision or negatively affect academic outcomes.

Refractive error
In the Yangjiang cohort, students underwent additional measurements of refractive error by noncycloplegic autorefraction with VX120 units (LUNENU S.A.S., Israel) (14).

Up to 3 measurements were taken. Measurements were excluded if the student's eyes were not focused on the visual targets during the examination. In the Shenzhen cohort, students underwent measurements of refractive error by noncycloplegic autorefraction with Topcon RM6000 autorefractors (Topcon Corp., Japan). The follow-up examinations were the same as those performed at baseline and were conducted by the same examiners with the same equipment. The baseline and follow-up examinations at each school were performed during the same month of the year. To measure the refractive condition, the eye refraction was determined three times: once during the baseline data collection during 2016–2017, once at a follow-up during 2017–2018, and once at another follow-up during 2018–2019. Spherical power and cylindrical power were recorded to calculate the spherical equivalent refraction (SER) [algebraic sum in diopters (D), sphere + 1/2 cylinder] for each eye. Myopia development was defined as the changes in eye refraction calculated as $SER_{2016–2017} − SER_{2018–2019}$. Vision conditions were defined in terms of the SER as follows: emmetropia (–0.49 D < SER <+0.49 D); myopia (SER ≤–0.5 D); and hyperopia (SER ≥+0.5 D). Myopia was further classified into low myopia (–2.99 D ≤ SER ≤–0.50 D), moderate myopia (–3.00 D ≤ SER ≤–5.99 D), and high myopia (–6.00 D ≤ SER ≤ less).

Academic performance

The most recent individual overall scores for nation-wide standard examinations according to grade were used as the outcome measures for academic performance with permission from the individual school. Academic performance in the Yangjiang cohort was collected in 2017, while that in the Shenzhen cohort was collected in 2019. All students in the same grade took the same exam. The total exam score for each student was recorded. The scores for each topic (Chinese, mathematics, and English) for the students from grade one to grade six were recorded for the subgroup analysis. We converted the total score and the scores of each subject to scores on a 0–100% grading scale for statistical analysis.

Covariate data

Body mass index (BMI), parental myopia, average screen time per day, average reading time per day, and average outdoor activity time per day are regarded as environmental factors of myopia (15-20). In the Yangjiang cohort, the BMI of each participant was measured once in 2016–2017 while he or she was standing without shoes on the TZG

measuring device (Yilian Technology); the height was measured to the nearest 0.1 cm with the Seca 899 scale (Seca), and the weight was measured to the nearest 0.1 kg (BMI = kg/m^2). In the Shenzhen cohort, BMI, paternal myopia, maternal myopia, average screen time per day, average reading time per day, and average outdoor activity time per day were collected through questionnaires during the last data collection in 2018–2019. Since the school classes outdoor and indoor times in different schools are relatively homogenous in China (21), we only investigated student's average after-school hours (outdoor activity time, reading time, and screen time) in the study. The average daily time spent outdoors during the school semester days (T_{school}) was calculated using the time spent outdoors on weekdays (T_{wd}) and on weekends (T_{we}): $T_{school} = (T_{wd} \times 5 + T_{we} \times 2) \div 7$. Time spent outdoors during the weekends (T_{we}) was used as a proxy for time spent outdoors during the summer and winter holidays (3 months per school year). Therefore, the average daily time spent outdoors during school years (T_{year}) was calculated as: $T_{year} = (T_{school} \times 9 + T_{we} \times 3) \div 12$.

Statistical analysis

The data of the right eyes were used in the analysis (64% of the articles obtained data from one eye, and the right eye was one of the selection criteria used for data collection) (22). Chi-square tests for trend were used to assess the changes in the proportions of students with hyperopia and myopia at successive grade levels. The prevalence rates of hyperopia and myopia were compared between sexes.

In the cross-sectional analyses, we examined the relationship between academic performance and refractive statuses among students from Yangjiang in grade one to grade nine, which represents the grades of compulsory education in China, according to the following steps. First, multilinear regressions were performed in a cross-sectional study to calculate the relationships between academic performance and refractive errors (myopia or hyperopia). Second, subgroup analysis was also performed to determine the association between the refractive errors and scores for each subject. Third, multilinear regressions were used to analyze the relationship between academic performance and exact eye refraction in students with myopia and hyperopia.

The longitudinal analyses were an extension of the cross-sectional analyses. First, we performed the longitudinal analyses in Shenzhen, a higher-tier city in southern China. Second, we collected data using a cohort design to assess the longitudinal changes in the correlation over time. Third,

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Table 1 Analyses of the proportion and trend of refractive error

Characteristics	Grade									Total	χ^2 for trend	P value
	1	2	3	4	5	6	7	8	9			
No of participants	327	11,84	630	27,751	1,120	885	222	137	104	32,360	–	–
Average age (years)	6.59	8.04	8.99	10.09	10.86	11.75	12.45	13.23	14.22	10.08	–	–
Mean (D)	–0.06	–0.08	–0.22	–0.35	–0.67	–0.91	–2.40	–2.85	–3.03	–0.40	–	–
Standard error (D)	0.73	0.56	0.70	0.89	1.27	1.52	2.08	2.16	2.11	1.00	–	–
Hyperopia (%)	6.42	2.62	2.54	1.11	0.89	0.68	2.25	1.46	0.00	1.23	45.03	<0.001
Myopia (%)	10.40	7.77	16.51	20.47	30.09	34.58	77.03	82.48	87.50	21.41	1,020.00	<0.001
Low myopia (%)	8.87	7.18	14.76	17.42	20.83	21.36	40.54	37.96	40.38	17.45	245.95	<0.001
Moderate myopia (%)	1.53	0.59	1.75	2.95	9.29	12.88	30.18	36.50	38.46	3.76	1,056.86	<0.001
High myopia (%)	0.00	0.00	0.00	0.10	0.00	0.34	6.31	8.03	8.65	0.20	465.22	<0.001

D, diopter.

we used a larger participant sample size from 114 schools. In longitudinal analyses, multilinear regressions were performed to calculate the relationships between academic performance and changes in eye refraction. Secondary longitudinal analyses were adjusted for additional covariates, including BMI, paternal myopia, maternal myopia, average screen time per day, average reading time per day, and average outdoor activity time per day.

In all multilinear regressions, academic performance was applied as the outcome variable, and gender, age, and BMI were included as covariates. All analyses were performed using SPSS (version 19.0, IBM Corp., New York, USA). The statistical tests were two-sided with a significance threshold of P<0.05.

Results

Study population

The study enrolled 33,343 students in 2016–2017. The students were attending 114 primary and junior high schools in China. A total of 723 participants were excluded from the analyses for low vision, high astigmatism, anisometropia, missing data or unreliable autorefraction values, 232 were excluded due to a history of wearing rigid contact lenses, medical treatment or diseases that could cause poor vision or negatively affect the academic outcomes, and 27 were excluded for being younger than 6 years or older than 15 years at baseline. Of the remaining 32,360 students,

1,971 participants were included from the Yangjiang cohort (1,086 males and 885 females), and 30,389 participants (17,274 males and 13,115 females) were included from the Shenzhen cohort.

The Shenzhen cohort was followed up for 2 years. Of the 30,389 students included in the analysis at baseline, 30,153 (99.22%) were re-examined in 2017–2018 (after 1 year) and 29,479 (97.01%) were re-examined in 2018–2019 (after 2 years).

In Yangjiang, the respective mean SER values for all subjects, males, and females were –0.40±–1.00 D (range, –8.83 to 6.80 D), –0.38±0.97 D (range, –8.30 to 6.80 D), and –0.42±1.03 D (range, –8.83 to 5.20 D), respectively. The overall prevalence rates of myopia and hyperopia were 12.14% and 1.23%, respectively.

The prevalence and trends of myopia and hyperopia for each grade are shown in *Table 1* and *Figure 1*. From grade one to grade nine, the prevalence of hyperopia decreased from 6.4% to 0% (χ^2=45.03, P<0.001), whereas the prevalence of myopia increased from 10.4% to 89.4% (χ^2=1,020.00, P<0.001). Furthermore, the growth rate peaked from grade six (34.58%) to grade seven (77.03%). All degrees of myopia increased from grade one to grade nine (low myopia, χ^2=245.95, P<0.001; moderate myopia, χ^2=1,056.86, P<0.001; high myopia, χ^2=465.22, P<0.001). Compared to the males, the females had a higher prevalence of myopia (χ^2=20.06, P<0.001) but a comparable prevalence of hyperopia (χ^2=0.08, P=0.78).
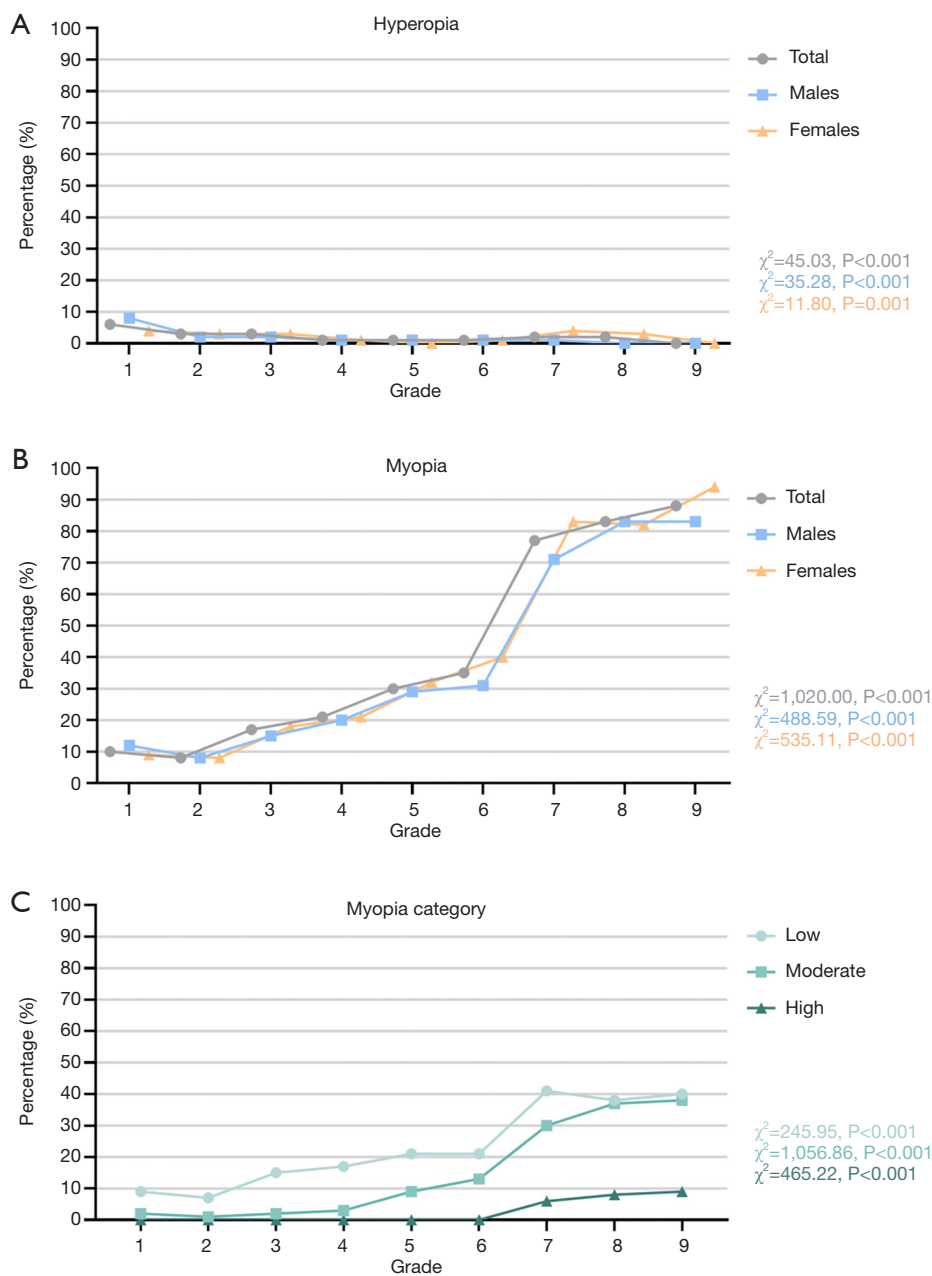
Figure 1 Analyses of the proportions and trends of refractive error stratified by gender. (A) From grade one to grade nine, the prevalence of hyperopia decreased (from 6.4% to 0%, χ^2=45.03, P<0.001). (B) The prevalence of myopia increased (from 10.4% to 89.4%, χ^2=1,020.00, P<0.001), and the growth rate peaked from grades six to seven (from 58.7% to 78.8%). (C) The proportion of each category of myopia increased from grades one to nine (low myopia, χ^2=245.95, P<0.001; moderate myopia, χ^2=1,056.86, P<0.001; high myopia, χ^2=465.22, P<0.001). Compared to the males, the females had a higher prevalence of myopia (χ^2=20.06, P<0.001) but a comparable prevalence of hyperopia (χ^2=0.08, P=0.78).

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Table 2 Multilinear regression of academic performance and refractive error (myopia or hyperopia) in the Yangjiang cohort

Grade	N	Hyperopia/β (P value)				Myopia/β (P value)			
		Total score	Chinese	Mathematics	English	Total score	Chinese	Mathematics	English
1	327	–0.04 (0.01)	–0.06 (0.02)	–0.02 (0.01)	NA	–0.01 (0.20)	–0.01 (0.20)	–0.003 (0.45)	NA
2	219	–0.02 (0.57)	–0.02 (0.67)	–0.02 (0.55)	NA	0.01 (0.18)	0.01 (0.25)	0.01 (0.21)	NA
3	151	0.03 (0.37)	0.05 (0.31)	0.01 (0.82)	0.03 (0.30)	0.002 (0.77)	0.004 (0.60)	0.003 (0.62)	–0.002 (0.66)
4	235	–0.02 (0.72)	–0.04 (0.36)	0.03 (0.55)	–0.03 (0.49)	0.01 (0.26)	0.01 (0.29)	0.01 (0.18)	0.01 (0.56)
5	278	–0.07 (0.21)	–0.08 (0.05)	–0.12 (0.16)	–0.01 (0.91)	0.01 (0.38)	0.01 (0.20)	0.01 (0.39)	0.002 (0.73)
6	298	–0.003 (0.97)	0.02 (0.78)	0.02 (0.88)	–0.06 (0.59)	0.02 (0.04)	0.02 (0.04)	0.02 (0.14)	0.03 (0.02)
7	222	0.07 (0.22)	NA	NA	NA	0.01 (0.61)	NA	NA	NA
8	137	NA	NA	NA	NA	0.04 (0.002)	NA	NA	NA
9	104	NA	NA	NA	NA	–0.02 (0.48)	NA	NA	NA

Data are presented β with the corresponding P value. NA: not available (lacking an adequate sample size for statistical analyses; students in grade one do not have English lessons).

Table 3 Multilinear regression of total academic performance and exact eye refraction stratified by refractive status in Yangjiang cohort

Grade	Hyperopia			Myopia		
	N	β	P value	N	β	P value
1	21	<0.001	1.00	34	0.002	0.81
2	10	0.04	0.31	36	–0.01	0.57
3	4	NA	NA	46	–0.02	0.08
4	6	–0.02	0.83	83	0.01	0.18
5	4	NA	NA	128	–0.01	0.35
6	3	NA	NA	175	–0.01	0.18
7	5	–0.27	0.77	175	–0.002	0.77
8	2	NA	NA	113	–0.01	0.19
9	0	NA	NA	93	–0.02	0.02

NA: not available (lacking an adequate sample size for statistical analyses).

Cross-sectional refractive power

Multilinear regressions showed that in grade one, the students with hyperopia had lower scores than did the students with emmetropia (β=–0.04, P=0.01). Specifically, on the Chinese language test and the math test, hyperopia was significantly associated with worse academic performance in grade one (β=–0.06, P=0.02; β=–0.02, P=0.01; *Table 2,3*).

Distributions of the students' academic performance in different grade groups are displayed in *Figure 2*. In grade six and grade eight, myopia was significantly correlated with better academic outcomes (β=0.020, P=0.038; β=0.041,

P=0.002). Specifically, on the Chinese language test and the English language test, students with myopia were less likely to have good academic performance in grade six than those without myopia (β=0.02, P=0.04; β=0.03, P=0.02). The refractive errors showed no significant correlation with academic performance in the other grades (*Tables 2,3*).

Furthermore, we stratified the data by refractive status and analyzed the relationship between academic performance and exact eye refraction in students with myopia and hyperopia. Notably, in grade nine, myopic students with low refractive value had significantly higher
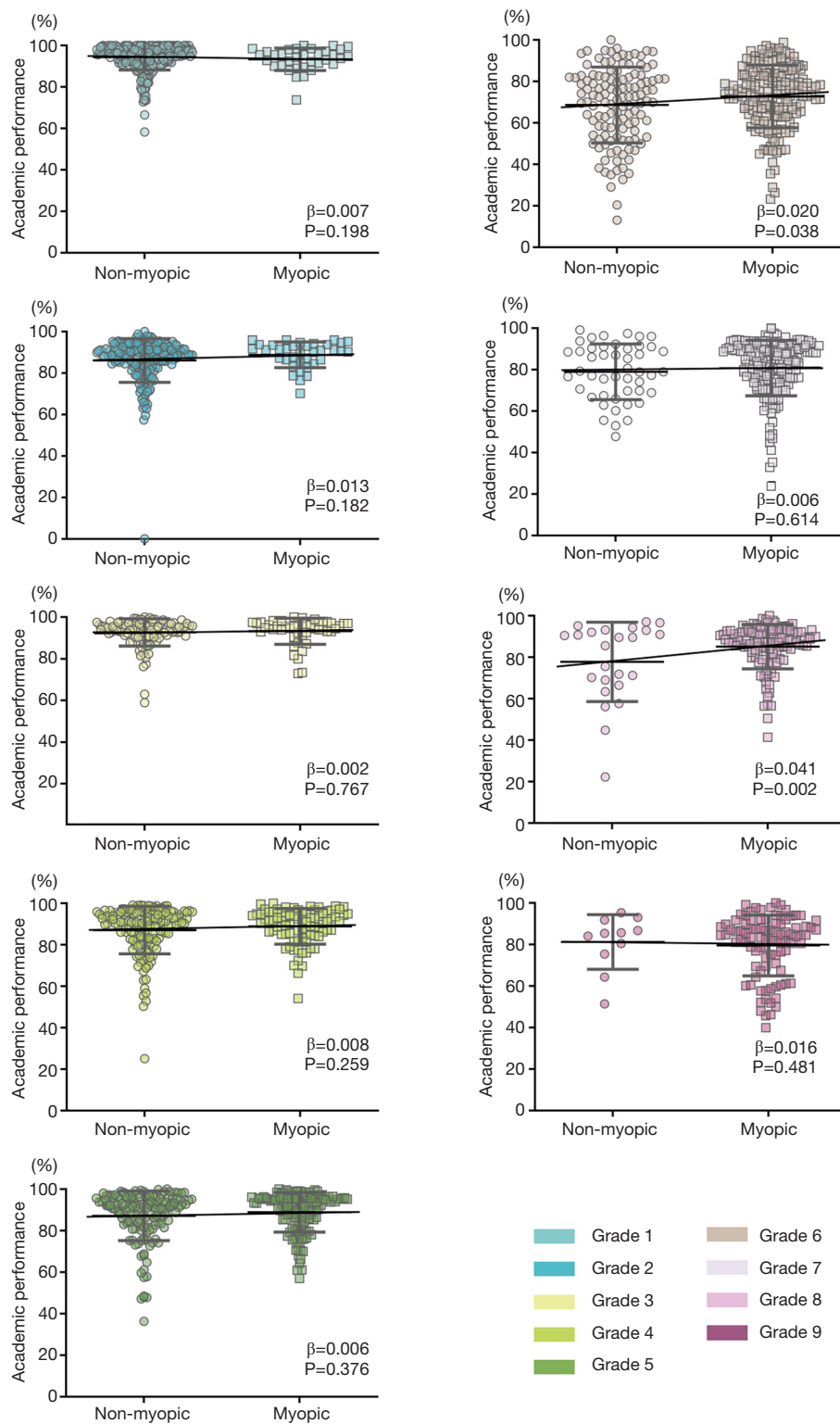
Figure 2 Scatter plots of the association between academic performance and the presence of myopia according to the cross-sectional analyses. In grade six and grade eight, myopia was significantly correlated with a better academic outcome (β=0.020, P=0.038; β=0.041, P=0.002). We converted the total score and the scores of each subject to scores on a 0–100% grading scale for statistical analysis.
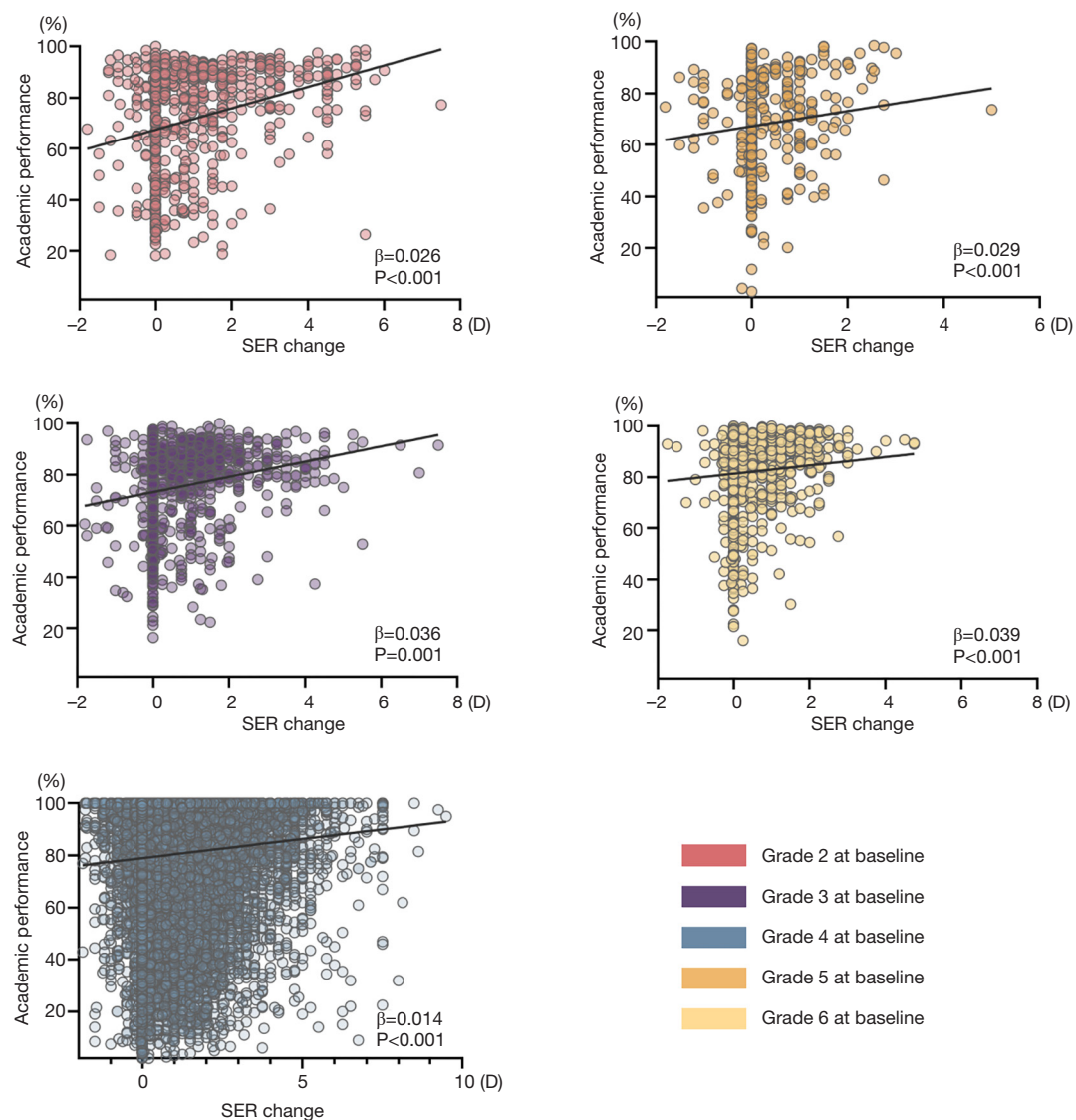
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Figure 3 Scatter plots of the association between academic performance and refractive changes according to the longitudinal analyses. As myopia developed, a faster refraction change was observed to be associated with better academic performance among students in all grades. We converted the total score and the scores of each subject to scores on a 0–100% grading scale for statistical analysis.

academic scores (β=−0.02, P=0.02), which means that high myopic students (<−6 D) are more likely to have higher academic scores from students with low and mean myopia (>−6 D).

Longitudinal change in eye refraction

Among the 29,479 participants who were followed, to avoid the impact of hyperopia on academic performance, we analyzed 29,146 students who were emmetropic or myopic

at baseline. Generally, in the follow-up period from 2018 to 2019, the changes in eye refraction positively correlated with academic performance in all grades (*Figure 3*, *Table 4*). Among the students in grade two, the multilinear model shows that faster myopia development of 1.00 D over 2 years was associated with a 3% increase in overall academic performance at the end of grade five (β=0.03, P<0.001). Using grade three as the baseline, a 1.00 D increase in myopia development over 2 years was associated with a 4% increase in academic performance at the end

Table 4 Multilinear regression of total academic performance and myopia development in the Shenzhen cohort

Grade at baseline	Grade at follow-up	N	β	P value
2	4	944	0.03	<0.001
3	5	467	0.04	0.001
4	6	26,315	0.01	<0.001
5	7	836	0.03	<0.001
6	8	584	0.04	<0.001

of grade six (β=0.04, P=0.001). In terms of the students in grade four, a faster refraction development (1.00 D over 2 years) was associated with an increase in the score by 1% (β=0.01, P<0.001). Furthermore, for students in grade five, a faster myopia development of 1.00 D per 2 years was associated with a 3% increase in academic performance at the end of grade seven (β=0.03, P<0.001). Similarly, faster myopia development was positively associated with academic performance among students in grade six (β=0.04, P<0.001).

The parents of 28,563 students (response rate 98.00%) completed the questionnaire. With respect to the covariates in the questionnaires, the association between myopia development and academic performance was still statistically significant after adjustment for BMI, paternal myopia, maternal myopia, average screen time per day, average reading time per day, and average outdoor activity time per day (grade two at baseline: β=0.03, P<0.001; grade three at baseline: β=0.04, P<0.001; grade four at baseline: β=0.01, P<0.001; grade five at baseline: β=0.03, P<0.001; grade six at baseline: β=0.04, P<0.001).

Discussion

In this study, for the first time, we comprehensively analyzed the association between refractive error and academic performance in Chinese students. We show that academic performance is related to refractive status among students in China. Specifically, in grade one, the prevalence of hyperopia is significantly correlated with poor academic performance in both the Chinese language and math. Emmetropization starts between the ages of 0.5 and 7 years, and students usually have mild hyperopia before enrolment in primary school, which may affect reading, writing, and concentration in the classroom (23,24). Among the students in grades six, eight, and nine, myopia was correlated with

better academic scores, possibly due to the heavy workload for entrance exam preparation at the end of grades six and nine. A previous longitudinal study reported that near-distance work can cause a mean refractive change of –0.63 D per year in students aged 6–17 years (25). We showed that among students in grade six, students with myopia have a significant positive correlation with better academic achievement in Chinese and English language classes, likely because language studies require reading and writing (26).

In light of the findings in the longitudinal analyses, among students in all grades with emmetropia or myopia, academic performance showed a strong positive correlation with refraction change over time. Children with higher academic performance have a higher prevalence and faster development of myopia, even after adjustments for BMI, outdoor activity time, screen time, reading time, and parental myopia.

Our observational analysis shows that the prevalence of myopia in grade one (10.40%, average age of 6.6 years) is higher than that reported in a previous investigation (≤5% for both males and females, aged 6 years) (27). Moreover, the prevalence of myopia in grade seven (77.03%, average age 12.5 years) reported in our study was also higher than that previously reported in 2004 (61%, 12 years of age) and 2011 (61.5%, 12 years of age) (28,29). These findings may indicate recent upward trend in myopia prevalence. Consistent with the findings of previous studies involving Chinese students, females had a higher prevalence of refractive errors (or myopia) than males, likely due to a shorter axial length and a steeper cornea (16,27). Additionally, compared to males, females were less likely to comply with lens-wearing recommendations due to esthetic concerns (30). Therefore, preventing myopia may be more challenging in female students than in male students.

Strengths and limitations

Our study has the following strengths. First, we included students aged 6 to 15 years, covering the age range of all schoolchildren in China. Second, we examined myopia as well as other refractive statuses so that the detailed distribution of academic performance by different refractive statuses could be assessed in the same population. Third, our subgroup analysis based on sex and subjects provides a more comprehensive overview of how refractive status affects academic performance. Fourth, we conducted two separate studies within two geographically distinct cities while considering the potential bias attributed to differences

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in education systems and levels of socioeconomical development. Fifth, our study included both cross-sectional analyses and longitudinal analyses to determine the changes in the correlations over time.

The limitations should be considered when interpreting the findings of this study. First, refractive error was determined by noncycloplegic autorefraction followed by subjective refraction. Obtaining refractive error in the absence of cycloplegia may lead to overestimations of the myopic or an underestimation of hyperopia (31). Therefore, some participants in the study may have been erroneously classified as myopic. Second, other factors associated with academic performance, including intelligence quotient (IQ) and parental educational attainment, were not considered in the analysis. Our findings merit further investigation with adjustments for these potentially confounding variables. Third, the method used to assess academic performance appears to be a single standardized exam at the end of the school year.

In conclusion, our studies show that academic performance is associated with the development of ametropia and myopia. Since the prevalence of hyperopia correlates with lower academic scores in grade one, while myopia correlates with better academic scores in grades six, eight, and nine, schools and parents are encouraged focus on appropriate correction of hyperopes of enrolled students with hyperopia to overcome learning difficulties. In addition, although the school system and parental expectations place massive demands on schoolchildren, all schoolchildren, typically those with a heavy study load before entering junior high school or senior high school, are encouraged to pay more attention to their eye health and study habits and take actions to prevent the development of refractive errors. Creating a healthy studying environment for students, such as integrating daylight into the school building design (32) and providing more outdoor activity (20), may help prevent and reduce refractive error development.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at http://dx.doi.org/10.21037/atm-20-8069

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Institutional Review Board of Zhongshan Ophthalmic Center (No. 2010175) and informed consent was taken from all the patients.

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