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Widening urban-rural and sex disparities in myopia with advancing school grade: a six-semester school-based screening study of 283,370 student-visits in Qujing, southwest China

Wengui Chen
Qilin District People's Hospital
Liyuan Zhang
Affiliated Qujing Hospital of Kunming Medical University
Jing Yan
Qujing University of Medicine & Health Sciences
Huixian Liu
Affiliated Qujing Hospital of Kunming Medical University
Yan Chen
Affiliated Qujing Hospital of Kunming Medical University
Difang Shi
The Third Affiliated Hospital of Kunming Medical University
Rui He
Affiliated Qujing Hospital of Kunming Medical University
Kang Wang
Affiliated Qujing Hospital of Kunming Medical University
Yueqi Wang
Affiliated Qujing Hospital of Kunming Medical University
Siqi Wang
The Third People's Hospital of Qujing
Fuling Qiu
20221010@kmmu.edu.cn

Affiliated Qujing Hospital of Kunming Medical University
Kang Du
Affiliated Qujing Hospital of Kunming Medical University

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Widening urban-rural and sex disparities in myopia with advancing school grade: a six-semester school-based screening study of 283,370 student-visits in Qujing, southwest China

Wengui Chen[1#], Liyuan Zhang[2#], Jing Yan[3#], Huixian Liu[2], Yan Chen[4], Difang Shi[5], Rui He[6], Kang Wang[2], Yueqi Wang[7], Siqi Wang[8], Fuling Qiu[9*], Kang Du[2*]

[1] Department of Otolaryngology, Qilin District People's Hospital, Yunnan, Qujing, 655000, China.

[2] Department of Neurology, Affiliated Qujing Hospital of Kunming Medical University/Qujing Central Hospital of Yunnan Province, Yunnan, Qujing, 655000, China.

[3] School of Medical Technology, Qujing University of Medicine & Health Sciences, Qujing 655100, Yunnan, China

[4] Department of Hematology, Affiliated Qujing Hospital of Kunming Medical University/Qujing Central Hospital of Yunnan Province, Yunnan, Qujing, 655000, China.

[5] Department of Thoracic Surgery I, The Third Affiliated Hospital of Kunming Medical University (Yunnan Cancer Hospital), Yunnan, Kunming, 650118, China.

[6] Department of Endocrinology and Metabolism, Affiliated Qujing Hospital of Kunming Medical University/Qujing Central Hospital of Yunnan Province Yunnan, Qujing, 655000, China.

[7] Department of Clinical Pharmacy, Affiliated Qujing Hospital of Kunming Medical University/Qujing Central Hospital of Yunnan Province, Yunnan, Qujing, 655000, China.

[8] Department of Clinical Pharmacy, The Third People's Hospital of Qujing , Yunnan, Qujing, 655000, China.

[9] Department of Geriatrics, Affiliated Qujing Hospital of Kunming Medical University/Qujing Central Hospital

of Yunnan Province, Yunnan, Qujing, 655000, China.

[#] **The first three authors contributed equally to this work.**

***Corresponding authors:** Kang Du (dukangyn@126.com) & Fuling Qiu (20221010@kmmu.edu.cn)

E-mail: Wengui Chen (chenwg040109@163.com); Liyuan Zhang (1135720305@qq.com); Jing Yan (yanjing040109@163.com); Huixian Liu (3037203674@qq.com); Yan Chen (1986512561@qq.com); Difang Shi (shidifang01@163.com); Rui He (2770238186@qq.com); Kang Wang (1422383259@qq.com); Yueqi Wang (3569983442@qq.com); Siqi Wang (wangsq8862@163.com)

Running title: Urban-rural and sex disparities in myopia among school children

Study design: School-based, multi-wave cross-sectional screening study (STROBE-compliant)

Abstract

Background: To determine the prevalence, distribution, and temporal trends of myopia among primary and secondary school students in Qujing, Yunnan, southwest China, and to characterise how urban-rural and sex disparities change across school grades.

Methods: A school-based, multi-wave cross-sectional screening study was conducted in Qujing across six consecutive semesters (spring 2023 to autumn 2025), covering students from preschool to grade 9. Uncorrected distance visual acuity and non-cycloplegic autorefraction were measured by trained teams. Myopia was defined as spherical equivalent refraction (SER) <= -0.50 D in either eye; severity was graded by the worse eye (low: -0.50 to > -3.00 D; moderate: <= -3.00 to > -6.00 D; high: <= -6.00 D). Anisometropia was defined as an absolute inter-eye SER difference >= 1.00 D. Prevalence and 95% confidence intervals (CIs) were calculated using the Wilson method; group comparisons used chi-square/Fisher, Wilcoxon, and Kruskal-Wallis tests with effect sizes; multivariable and interaction analyses, including threshold-specific logistic regression for myopia severity after assessment of the proportional-odds assumption, were performed with Benjamini-Hochberg correction.

Results: A total of 283,370 records were analysed. Overall myopia prevalence was 34.3% (95% CI 34.2-34.5); high myopia affected 2.5% of participants and anisometropia 11.7% (95% CI 11.5-11.8). Prevalence rose steeply with grade, from 4.4% in grade 1 to 61.4% in grade 9 (adjusted OR per grade 1.56; trend $P < 0.001$; non-linearity $P < 0.001$; eta-squared = 0.194). Crude prevalence was higher in rural than urban students (39.4% vs. 28.6%), but after adjustment for grade the rural risk was lower (OR 0.78, 95% CI 0.76-0.79), indicating that the crude reversal largely reflected grade composition. The urban-rural gap widened with grade

(interaction P < 0.001), the within-grade urban excess rising from OR 1.00 (grade 1) to 1.55 (grade 8). Girls had higher prevalence than boys (36.6% vs. 32.3%; OR 1.30, 95% CI 1.27-1.32), and the sex gap was generally more pronounced in higher grades (interaction P < 0.001), from OR 0.98 (grade 1) to 1.47 (grade 9).

Conclusions: Myopia is a substantial burden among school students in Qujing, with non-negligible high myopia and anisometropia. Urban-rural and sex disparities in myopia are not static but are generally more pronounced in higher grades, supporting grade-targeted, tiered, and precision prevention targeting higher-risk grades and girls while improving equitable access to screening and care in rural areas.

Keywords: myopia; prevalence; school children; urban-rural disparity; sex disparity; anisometropia; school screening

Introduction

Myopia has become one of the leading causes of refractive error and irreversible visual impairment worldwide. It is projected that by 2050, approximately half of the global population will be myopic, with about 10% having high myopia [1]. The burden is particularly pronounced in East Asia, where the prevalence of myopia among Chinese children and adolescents has long been among the highest globally and continues to rise [2,3]. National systematic reviews have shown that the myopia rate among children and adolescents aged 7-18 years has already exceeded 50% and is expected to continue climbing over the coming decades [3,4]. Myopia not only affects academic performance and quality of life, but high myopia is also closely associated with blinding complications such as retinal detachment, maculopathy, and glaucoma, imposing a substantial burden on individuals, families, and society [5].

The onset and progression of myopia are influenced by both genetic and environmental factors. Intensive near work, excessive academic workload, insufficient outdoor activity, and prolonged screen time are considered key drivers of the rapid increase in prevalence in recent years [6-8]. Owing to significant regional differences in educational systems, urbanisation levels, economic development, and lifestyles, the epidemiology of myopia varies across China: studies in major eastern coastal cities such as Beijing, Shanghai, and Guangzhou have generally reported higher prevalence rates [9], and urban-rural disparities have also been observed [10-12]. Additionally, lifestyle changes during the COVID-19 pandemic, including home confinement, have been shown to accelerate myopia progression in children [13]. However, most large-scale studies have been conducted in economically developed urban areas and have predominantly employed single-time-point cross-sectional designs; multi-wave, large-sample

surveillance evidence from the less-developed mountainous regions of southwest China--where economic development, healthcare accessibility, health literacy, and educational intensity differ markedly from eastern cities--remains relatively scarce [14,15]. Furthermore, existing studies have largely focused on overall prevalence and its static correlates, with limited attention to how myopia disparities between subpopulations (e.g., urban vs. rural, male vs. female) evolve dynamically across grades, and few have simultaneously reported indicators closely related to visual function impairment, such as high myopia and anisometropia [16,17].

Qujing Municipality is located in eastern Yunnan Province and encompasses multiple counties (cities, districts) with considerable variation in urban-rural development levels, making it an ideal setting for examining the epidemiological characteristics of myopia among children and adolescents in less-developed mountainous areas. Leveraging citywide vision screening data from primary and secondary schools collected over six consecutive semesters from spring 2023 to autumn 2025, we conducted this large-sample study with the following objectives: (1) to describe the prevalence and temporal trends of myopia, high myopia, and anisometropia among school students in Qujing; (2) to quantify urban-rural and sex disparities and examine whether these disparities change systematically across grades; and (3) to identify factors associated with myopia and its severity. The findings provide an evidence base for precision myopia prevention in southwest China and other underdeveloped regions nationwide.

Methods

Study design and participants

This was a school-based, multi-wave cross-sectional vision screening study using data

from the Qujing Municipal Student Vision Health Monitoring Project. The study population comprised students enrolled from preschool through grade 9 in schools within Qujing Municipality. Screening was conducted over six consecutive semesters (spring 2023, autumn 2023, spring 2024, autumn 2024, spring 2025, and autumn 2025). Because multi-wave screening meant that the same student could be included in different semesters, this study used "student-visits" (i.e., individual complete screening records) as the unit of analysis. Inclusion criteria: enrolled students who completed uncorrected distance visual acuity testing and autorefraction with complete data. Exclusion criteria: (1) organic eye disease or history of ocular surgery/trauma affecting vision; (2) active ocular inflammation or infection at the time of screening; (3) missing or implausible key data (e.g., unavailable refraction values or SER values outside plausible ranges). Students undergoing myopia control interventions (e.g., low-concentration atropine, orthokeratology, defocus lenses) were not excluded, to ensure prevalence estimates reflected real-world conditions, but were separately recorded during screening.

Vision screening and refraction measurement

Screening was performed in standardised on-site locations (large classrooms or auditoriums) by teams of ophthalmologists and licensed optometrists who had received unified training. Uncorrected distance visual acuity was assessed using a standard logarithmic visual acuity chart, monocularly from right to left eye with the fellow eye covered, and recorded in decimal notation. Objective refractive status was measured using an autorefactor with keratometry function; three consecutive measurements were taken per eye and averaged, with additional measurements performed if the standard deviation exceeded 0.50 D. Cycloplegia

was not performed owing to operational and safety considerations in the school-based setting (i.e., non-cycloplegic refraction). Students identified with abnormal vision or suspected myopia were issued individualised reports and referred to designated medical institutions for cycloplegic refraction and further confirmation; confirmed results were fed back for use in statistical analyses.

Definition of outcomes

Following relevant guidelines from the National Health Commission of China [18], refractive status was determined based on spherical equivalent refraction (SER, calculated as sphere power + half cylinder power). Myopia was defined as SER <= -0.50 D in either eye. Myopia severity was graded according to the worse eye: low myopia (-0.50 D to > -3.00 D), moderate myopia (<= -3.00 D to > -6.00 D), and high myopia (<= -6.00 D). Hyperopia was defined as SER >= +0.50 D and similarly graded. Anisometropia was defined as an absolute inter-eye SER difference >= 1.00 D. Bilateral myopia status was classified as bilateral non-myopia, unilateral myopia (only one eye with SER <= -0.50 D), or bilateral myopia. Observation periods were categorised by year and semester (spring/autumn).

Statistical analysis

Statistical analyses were performed using R version 4.4.0 and Stata version 17.0. For continuous variables, normality was first assessed using the Shapiro-Wilk test; SER, age, and other continuous measures were found to be non-normally distributed in the overall population (all $P < 0.001$) and were therefore described using mean +/- standard deviation, median (25th, 75th percentiles, P25-P75), and range. Categorical variables were described as counts (proportions). Ninety-five percent confidence intervals (CIs) for binary outcomes (myopia rate,

high myopia rate, anisometropia rate) were calculated using the Wilson method. Group comparisons were selected based on variable type and distribution: (1) for categorical variables, Pearson's chi-square test was used to assess between-group differences, supplemented by Fisher's exact test based on Monte Carlo simulation (5,000 replicates) to ensure reliability with small samples; (2) for continuous variables, given the markedly skewed distribution of SER and other measures, the Wilcoxon rank-sum test was used for two-group comparisons, and the Kruskal-Wallis H test for multi-group comparisons, with Kruskal-Wallis eta-squared reported as the effect size to evaluate the practical magnitude of between-group differences.

Multivariable logistic regression was used to estimate the independent effects of urban-rural location, sex, grade, and observation period on myopia, high myopia, and anisometropia. Interaction terms (urban-rural x grade, sex x grade) were included to test for interaction effects, and stratified adjusted odds ratios were calculated within each grade to characterise the dynamic evolution of disparities across grades. An ordinal logistic regression model was initially fitted for myopia severity (non-myopia < low < moderate < high myopia). Because the proportional odds assumption was rejected ($P < 0.001$), three threshold-specific multivariable logistic regression models were used for the severity analysis. Generalised additive models were used to test for non-linear associations with grade. All hypothesis tests were two-sided. For multiple comparisons and multiple testing, the Benjamini-Hochberg (BH) method was applied to control the false discovery rate, with adjusted $P < 0.05$ considered statistically significant.

Ethics

This study was reviewed and approved by the relevant ethics review bodies in Qujing

Municipality and was conducted in strict accordance with the Declaration of Helsinki. Informed consent was obtained from students and their parents or legal guardians prior to screening. Individual screening results were confidentially communicated to schools and parents.

Results

Screening coverage and participant characteristics

A total of 283,370 screening records with complete refraction data were collected across six semesters. The mean age of participants was 9.18 +/- 2.27 years (median 9 years, range 4-25 years; n = 47,681). The right-eye SER was -0.91 +/- 1.75 D and the left-eye SER was -0.84 +/- 1.72 D, with medians of 0.00 D for both eyes (Table 1). Among all student-visits, 52.9% were male and 47.1% were female; 53.1% were from rural areas and 46.9% from urban areas; lower primary grades predominated, with grades 1-3 accounting for 40.3% of the sample (Table 2). The number of student-visits per semester was as follows: spring 2023, 22,265 (7.9%); autumn 2023, 49,043 (17.3%); spring 2024, 33,033 (11.7%); autumn 2024, 58,290 (20.6%); spring 2025, 43,534 (15.4%); autumn 2025, 77,205 (27.2%). The upper age of 25 years requires verification against enrolment records and eligibility criteria.

Overall myopia prevalence and subgroup comparisons

The overall myopia prevalence was 34.3% (95% CI 34.2-34.5%; 97,324/283,370). Among myopic individuals, low, moderate, and high myopia accounted for 55.4%, 37.2%, and 7.4%, respectively; using all participants as the denominator, the prevalence of high myopia was 2.5% (Table 2). Among hyperopic individuals, low, moderate, and high hyperopia accounted for

55.5%, 24.2%, and 20.3%, respectively (Table 2). By sex, the myopia rate was higher in girls (36.6%) than in boys (32.3%); by urban-rural location, rural students had a higher rate (39.4%) than urban students (28.6%); by eye, the right eye (32.6%) had a slightly higher rate than the left eye (31.5%) (Table 3, Figure 1). Differences in myopia prevalence across urban-rural location, sex, grade, and observation period were all statistically significant (all $P < 0.001$), whereas the distribution of myopia severity did not differ significantly by sex ($P = 0.765$) (Table 4). SER also differed significantly across urban-rural location, sex, grade, and observation period (all $P < 0.001$) (Table 5).

Changes in myopia prevalence by observation period and grade

Overall myopia prevalence showed a general upward trend, with periodic fluctuations characterised by higher rates in autumn semesters than in spring semesters: the rate increased from 29.6% in spring 2023 to 37.5% in autumn 2025 (Table 3, Figure 2). In the multivariable model, using 2023 as the reference, the myopia risk was elevated in 2024 and 2025 (OR = 1.02, $P = 0.082$; OR = 1.16, $P < 0.001$, respectively); for each standard deviation increase in observation period, the myopia risk increased by 6% (OR = 1.06, 95% CI 1.05-1.07) (Table 6b, Figure 4A). Notably, although unadjusted autumn rates were consistently higher than the corresponding spring rates each year, after adjustment for grade, urban-rural location, and sex, the autumn relative to spring myopia risk was actually slightly lower (OR = 0.86, 95% CI 0.84-0.87), suggesting that the apparent "higher autumn" pattern was largely attributable to differences in grade composition between the two screening seasons. The adjusted "higher spring" pattern is consistent with the seasonal rhythm reported in previous studies, in which axial length grows faster during winter months with less sunlight and slows during summer

months.

Myopia prevalence was 5.9% in preschool and increased progressively from 4.4% in grade 1, 10.9% in grade 2, 20.3% in grade 3, 33.2% in grade 4, 42.9% in grade 5, 51.1% in grade 6, 57.9% in grade 7, 59.9% in grade 8, and 61.4% in grade 9 (Table 3, Figure 2D, Figure 3A). Using grade 1 as the reference, the adjusted ORs for grades 2 through 9 increased from 2.62 (grade 2) to 40.08 (grade 9) (Table 6b); trend analysis showed that each one-grade increase was associated with a 56% increase in myopia risk (OR = 1.56, 95% CI 1.55-1.57) (Table 6c), with significant non-linearity (linear vs. 3-df natural spline model comparison $P < 0.001$), indicating that prevalence increased most rapidly during the middle-to-upper primary school years. The effect size of grade on SER was large (eta-squared = 0.194), whereas those for urban-rural location and sex were small (rank-biserial correlation coefficients of 0.111 and 0.036, respectively) (Table 6d).

Myopia severity composition and grade distribution of high myopia

With advancing grade, the severity composition among myopic students progressively shifted towards moderate and high myopia: the proportion of low myopia decreased, while the proportions of moderate and high myopia increased (Figure 3B). The high myopia rate increased from 0.2% in grade 1 to 8.5% in grade 9 (Figure 4D). Multivariable analysis showed that rural students had lower adjusted odds of high myopia (OR = 0.87, 95% CI 0.82-0.93) and girls had higher adjusted odds (OR = 1.18, 95% CI 1.13-1.24); the odds of high myopia increased sharply with grade, with the OR for grade 9 versus preschool reaching 18.71 (95% CI 2.62-133.71) (Table S1).

Urban-rural disparities: crude "reversal" and grade-dependent widening

Without adjustment, rural students had a markedly higher myopia rate than urban students (39.4% vs. 28.6%), presenting a counterintuitive "rural higher than urban" gradient (Table 3, Figure 1B). However, within-grade comparisons after adjustment for sex and observation period consistently showed that urban students had a higher myopia risk than rural students: the rates were nearly identical in grade 1 (4.4% vs. 4.5%; OR = 1.00, 95% CI 0.91-1.11), and the urban advantage increased progressively from grade 2 onwards, reaching OR = 1.55 (1.42-1.68) in grade 8 and 1.51 (1.35-1.69) in grade 9 (Table 7, Figure 5A). The urban-rural x grade interaction test yielded $P < 0.001$. In the multivariable model, the adjusted OR for rural versus urban was 0.78 (0.76-0.79) (Table 6b). This phenomenon of "crude reversal with adjusted reversion" indicates that the higher crude myopia rate among rural students in Qujing was primarily attributable to the larger proportion of older (particularly junior high school) students in the rural screening population, rather than to a genuinely higher susceptibility to myopia among rural students within the same grade.

Sex disparities and their widening with grade

The myopia prevalence was higher in girls than in boys (36.6% vs. 32.3%); after adjustment, girls had 1.30 times the myopia risk of boys (95% CI 1.27-1.32). The sex gap widened significantly with grade (sex x grade interaction $P < 0.001$): the male-female difference was minimal or absent in grades 1-2 (grade 1 OR = 0.98, P = 0.643; grade 2 OR = 1.07, P = 0.050), but from grade 3 onwards the female advantage became pronounced and continued to increase, with ORs of 1.27 in grade 4, 1.38 in grade 6, and 1.47 (1.39-1.56) in grade 9 (Table S2, Figure 4B). Girls also had higher risks for high myopia and anisometropia

(ORs of 1.18 and 1.21, respectively).

Bilateral myopia status and anisometropia

Among all student-visits, bilateral non-myopia accounted for 65.7%, unilateral myopia for 4.6%, and bilateral myopia for 29.8% (Table S3, Figure 6A). The prevalence of anisometropia (absolute inter-eye SER difference >= 1.00 D) was 11.7% (95% CI 11.5-11.8%). The anisometropia rate increased sharply with grade, from below 5% in grade 1 to over 20% in grade 9 (Figure 6B). Multivariable analysis showed that rural location (OR = 0.86, 95% CI 0.83-0.88) and female sex (OR = 1.21, 95% CI 1.18-1.24) were associated with anisometropia, and the risk increased significantly with grade (grade 9 vs. preschool OR = 8.47, 95% CI 4.30-19.96) (Table S4).

Factors associated with myopia severity

Because the proportional odds assumption was not satisfied ($P < 0.001$), severity associations were assessed using three threshold-specific multivariable logistic regression models: any myopia versus none, moderate/high myopia versus none/low, and high myopia versus all lower categories. The adjusted ORs for rural versus urban residence were 0.78, 0.75, and 0.87, respectively; for female versus male sex, they were 1.30, 1.21, and 1.18. The grade 9 versus grade 1 ORs were 40.08, 105.58, and 51.38 across these thresholds (Figure 7; Supplementary Table S6).

Discussion

Principal findings

In this study encompassing over 280,000 screening records spanning three years and six

semesters in Qujing Municipality, we observed the following: (1) the overall myopia prevalence among primary and secondary school students was 34.3% and varied across screening periods, with high myopia and anisometropia affecting 2.5% and 11.7% of students, respectively; (2) myopia prevalence rose rapidly with grade, and grade was the strongest risk factor; (3) the crude rate was higher in rural than in urban students, but after adjustment for grade, urban students had higher odds, and the urban-rural gap was generally more pronounced in higher grades, with non-monotonic variation; and (4) girls had a higher myopia risk than boys, and the sex gap was generally more pronounced in higher grades. The latter two findings indicate that myopia disparities between subpopulations are not constant but tend to be more pronounced in higher grades--providing direct evidence for the principle that myopia prevention should be tailored by timing, location, and individual characteristics.

Comparison with previous studies

The overall myopia prevalence of 34.3% obtained in this study was lower than the 36.97% reported among primary school students in Guangzhou during the same period [17], and also lower than the levels reported in Shanghai and other eastern cities as well as the national average for children and adolescents aged 7-18 years [3,4]. It was comparable to results reported from some central Chinese cities [10,11] and substantially higher than low-prevalence regions such as rural Mongolia. These differences are closely related to the heterogeneity in socioeconomic development, educational intensity, and average daily outdoor activity time across regions [6-8].

Notably, the direction of the urban-rural myopia gradient observed in this study differs from that reported in classical studies: most existing studies have reported higher myopia rates

among urban than rural children and adolescents [10-12], whereas the unadjusted crude myopia rate in Qujing showed a rural-higher-than-urban pattern. Further stratified analysis confirmed that this "reversal" was primarily driven by differences in grade composition between the urban and rural screening populations--the rural sample contained a substantially higher proportion of junior high school students, and because myopia prevalence increases steeply with grade, the unadjusted crude rate was artificially inflated. When comparisons were made within the same grade after adjusting for confounders, urban students had significantly higher myopia risk than rural students, consistent with the classical finding that urban areas have higher myopia rates than rural areas [10-12]. Our results underscore the necessity of adjusting for grade (age) composition when analysing urban-rural disparities in myopia, and also indicate that between-group comparisons based solely on crude rates may yield misleading conclusions.

Widening urban-rural gap with grade and its explanation

We further found that the urban-rural myopia gap was generally more pronounced in higher grades, with non-monotonic variation: the within-grade urban excess in myopia risk was near zero in grade 1 (adjusted OR = 1.00) and approximately 1.5-fold in grades 8-9, with fluctuations between grades, displaying a characteristic "scissors divergence" pattern. The core driving mechanism underlying this phenomenon is closely related to the progressive accumulation of differences in near-work behaviour, educational environment exposure, and access to myopia control resources between urban and rural students as schooling advances: with increasing academic burden in the middle-to-upper grades, urban students generally engage in more near-work time and less outdoor activity than rural students [6-8,10], and the cumulative effects of prolonged near work directly accelerate myopia progression in urban

students. Meanwhile, rural areas face shortcomings in myopia prevention service delivery, with lower coverage of vision screening and reduced accessibility to myopia control interventions such as low-concentration atropine and orthokeratology; the absence of a complete "screening-referral-intervention" loop further amplifies the urban-rural disparity in myopia burden. Additionally, the urban-rural difference varied significantly across years and seasons (all interaction $P < 0.001$), suggesting that this gap remains in dynamic evolution. The underlying mechanisms require further validation using longitudinal data on visual behaviour and environmental exposures, providing empirical evidence for grade-specific and population-specific precision prevention strategies.

Widening sex disparity

Our results showed that girls had a significantly higher risk of myopia than boys (OR = 1.30), and this sex difference emerged from grade 3 and progressively widened with advancing grade. These findings are consistent with reports of sex differences in myopia and axial elongation from East Asia [19]. For example, a Japanese study based on the national health insurance claims database showed that myopia prevalence among children aged <=14 years was consistently higher in girls than in boys from age 8 onwards [20]; a South Korean study based on the National Health and Nutrition Examination Survey also found that myopia prevalence in girls increased significantly over the past decade, while it remained relatively stable in boys [21]. The potential mechanisms underlying this difference may be related to the earlier onset of puberty in girls and the correspondingly earlier period of rapid axial elongation: endocrine changes around puberty can accelerate axial lengthening, thereby promoting myopia onset and progression [7,19]. Additionally, girls are more likely to develop prolonged, near-

work reading and writing behaviour patterns, and generally have shorter daily outdoor activity time, whereas adequate natural light exposure and outdoor activity are protective against myopia [6,7].

Our finding that sex differences in myopia were not significant in the lower grades suggests that myopia prevention interventions should be initiated as early as possible, with particular attention to female students. For example, implementing targeted visual health education and behavioural interventions before grade 3 may effectively reduce the risk of subsequent widening of the sex disparity. For female students, particular emphasis should be placed on increasing outdoor activity time, optimising visual habits (e.g., looking into the distance for 5 minutes every 40 minutes), and ensuring regular vision screening to achieve more precise myopia control.

Public health significance of high myopia and anisometropia

This study showed that the overall prevalence of high myopia among primary and secondary school students in Qujing reached 2.5%, with a rapid increase with grade, reaching 8.5% by grade 9--equivalent to one in every 12 ninth-grade students being affected by high myopia. The overall prevalence of anisometropia was 11.7%, also increasing sharply with grade, exceeding 20% by grade 9. Both are important risk factors for irreversible visual function impairment in children and adolescents: high myopia, as an independent risk factor for blinding complications such as retinal detachment, maculopathy, and glaucoma, causes visual impairment that is difficult to reverse in adulthood, imposing long-term disease burden on individuals, families, and society [5]; anisometropia can lead to amblyopia, binocular visual fusion dysfunction, and persistent visual fatigue, which not only affect academic performance

but may also impose long-term restrictions on occupational choices (e.g., aviation and precision manufacturing, which require high-level binocular visual function) [16,17].

Notably, these two important visual health indicators have often been overlooked in previous prevention systems centred on "overall myopia prevalence." Our results suggest that myopia prevention in children and adolescents should establish a multi-dimensional assessment framework encompassing "prevalence-severity-binocular balance," incorporating high myopia and anisometropia into routine screening, follow-up monitoring, and public health intervention evaluation indicators to achieve precision management across the full course of myopia.

Strengths and limitations

The strengths of this study include: a large sample size (283,370 student-visits) covering both urban and rural areas and all grades from preschool through grade 9; continuous monitoring over six semesters, enabling assessment of temporal trends and seasonal fluctuations; simultaneous reporting of multiple dimensions including myopia, myopia severity, high myopia, anisometropia, and bilateral status; and the use of effect sizes and interaction analyses, which better reflect practical differences than P-values alone. Limitations include: (1) non-cycloplegic refraction may overestimate myopia prevalence in younger children, although strict diagnostic criteria and referral verification procedures were employed; (2) multi-wave screening used "student-visits" as the unit of analysis, meaning the same student could be included repeatedly, and individual-level incidence and progression could not be tracked; (3) the cross-sectional design precludes causal inference, and individual-level variables such as near-work behaviour, outdoor activity, and parental myopia were unavailable; and (4) the

sample was drawn from Qujing Municipality, and caution is needed in generalising to other regions.

Conclusions

Myopia is a substantial burden among school students in Qujing, with non-negligible high myopia and anisometropia. Urban-rural and sex disparities in myopia are not static but are generally more pronounced in higher grades, supporting grade-targeted, tiered, and precision prevention targeting higher-risk grades and girls while improving equitable access to screening and care in rural areas.

Declarations

Ethics approval and consent to participate

The studies involving human participants were conducted in accordance with the ethical principles of the Helsinki Declaration and approved by the Ethics Committee of Qujing Central Hospital. Written informed consent was obtained from students and their parents or legal guardians prior to screening.

Consent for publication

Written informed consent for publication of identifying images or other personal or clinical details was obtained from the participants in this study.

Availability of data and material

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding authors.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Authors' contributions

FQ & LZ: acquisition of data, completion of statistical analysis, drafting of the initial manuscript, and writing of the final manuscript. JY: acquisition of data, study concept and design, completion of statistical analysis, and critical revision of the manuscript. HL, YC, DS, RH, KW, YW & SW: study concept and design, and critical revision of the manuscript. WC & KD: data review, interpretation of results, and revision of the initial draft. All authors contributed to the article and approved the submitted version.

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Tables

Table 1. Descriptive statistics of continuous variables in the study population

Variable	Valid n	Mean ± SD	Median (P25, P75)	Range
Age (years)	47,681	9.18 ± 2.27	9.00 (7.00, 11.00)	4.00–25.00
Right eye SER (D)	283,370	-0.91 ± 1.75	0.00 (-1.50, 0.00)	-25.50–16.00
Left eye SER (D)	283,370	-0.84 ± 1.72	0.00 (-1.38, 0.00)	-29.00–16.12

Note: SER, spherical equivalent refraction; P25, P75, 25th and 75th percentiles. Age was only partially recorded (n=47,681).

Table 2. Frequency distribution of categorical variables

Variable	Category	n (%)
Observation period	Spring 2023	22,265 (7.9%)
	Autumn 2023	49,043 (17.3%)
	Spring 2024	33,033 (11.7%)
	Autumn 2024	58,290 (20.6%)
	Spring 2025	43,534 (15.4%)
	Autumn 2025	77,205 (27.2%)
Residence	Rural	150,556 (53.1%)
	Urban	132,814 (46.9%)
Grade	Preschool	185 (0.1%)
	Grade 1	39,863 (14.1%)
	Grade 2	37,627 (13.3%)
	Grade 3	36,486 (12.9%)
	Grade 4	33,099 (11.7%)
	Grade 5	32,140 (11.4%)
	Grade 6	28,766 (10.2%)
	Grade 7	30,199 (10.7%)
	Grade 8	24,678 (8.7%)
	Grade 9	19,923 (7.0%)
Sex	Female	133,489 (47.1%)
	Male	149,881 (52.9%)
Myopia severity (among myopic)	Low myopia	53,962 (55.4%)
	Moderate myopia	36,157 (37.2%)
	High myopia	7,205 (7.4%)
Hyperopia severity (among hyperopic)	Low hyperopia	2,402 (55.5%)
	Moderate hyperopia	1,049 (24.2%)
	High hyperopia	878 (20.3%)

Note: Percentages in parentheses. Myopia severity denominator = myopic subjects; hyperopia severity denominator = hyperopic subjects. Grade was missing for 404 records (84 myopic and 320 non-myopic); grade-specific analyses exclude these records.

Table 3. Myopia prevalence by characteristics

Grouping variable	Group	Valid n	Myopic n	Prevalence (95% CI)
Overall	All	283,370	97,324	34.3% (34.2%–34.5%)
Observation period	Spring 2023	22,265	6,589	29.6% (29.0%–30.2%)
	Autumn 2023	49,043	16,762	34.2% (33.8%–34.6%)
	Spring 2024	33,033	9,864	29.9% (29.4%–30.4%)
	Autumn 2024	58,290	20,646	35.4% (35.0%–35.8%)
	Spring 2025	43,534	14,522	33.4% (32.9%–33.8%)
	Autumn 2025	77,205	28,941	37.5% (37.1%–37.8%)
Grade	Preschool	185	11	5.9% (3.4%–10.3%)
	Grade 1	39,863	1,762	4.4% (4.2%–4.6%)
	Grade 2	37,627	4,085	10.9% (10.5%–11.2%)
	Grade 3	36,486	7,406	20.3% (19.9%–20.7%)
	Grade 4	33,099	11,004	33.2% (32.7%–33.8%)
	Grade 5	32,140	13,790	42.9% (42.4%–43.4%)
	Grade 6	28,766	14,698	51.1% (50.5%–51.7%)
	Grade 7	30,199	17,479	57.9% (57.3%–58.4%)
	Grade 8	24,678	14,778	59.9% (59.3%–60.5%)
	Grade 9	19,923	12,227	61.4% (60.7%–62.0%)
Residence	Rural	150,556	59,351	39.4% (39.2%–39.7%)
	Urban	132,814	37,973	28.6% (28.3%–28.8%)
Sex	Female	133,489	48,883	36.6% (36.4%–36.9%)
	Male	149,881	48,441	32.3% (32.1%–32.6%)

Note: Myopia defined as SER ≤ -0.50 D in either eye; 95% CI calculated using Wilson method. Grade missing for 404 cases.

Table 4. Group comparisons for myopia and myopia severity

Outcome	Grouping variable	Test	Statistic	df	P	Adjusted P (BH)
Myopia (SER)	Residence	Pearson χ^2	3670.459	1	<0.001	<0.001
Myopia (SER)	Sex	Pearson χ^2	578.913	1	<0.001	<0.001
Myopia (SER)	Grade	Fisher exact	—	—	<0.001	<0.001
Myopia (SER)	Observation period	Pearson χ^2	904.488	5	<0.001	<0.001
Myopia severity	Residence	Pearson χ^2	1202.734	2	<0.001	<0.001
Myopia severity	Sex	Pearson χ^2	0.536	2	0.765	0.765
Myopia severity	Grade	Fisher exact	—	—	<0.001	<0.001

Note: Fisher exact test used when expected cell count insufficient (Monte Carlo simulation 5,000 iterations); BH, Benjamini-Hochberg correction.

493 **Table 5. Group comparisons of spherical equivalent refraction**

Outcome	Grouping variable	Test	Statistic	df	P	Adjusted P (BH)
Right eye SER	Residence	Wilcoxon rank-sum	1.12×10^{10}	—	<0.001	<0.001
Left eye SER	Residence	Wilcoxon rank-sum	1.11×10^{10}	—	<0.001	<0.001
Right eye SER	Sex	Wilcoxon rank-sum	1.04×10^{10}	—	<0.001	<0.001
Left eye SER	Sex	Wilcoxon rank-sum	1.04×10^{10}	—	<0.001	<0.001
Right eye SER	Grade	Kruskal-Wallis	54,938.919	9	<0.001	<0.001
Left eye SER	Grade	Kruskal-Wallis	48,806.829	9	<0.001	<0.001
Right eye SER	Observation period	Kruskal-Wallis	813.763	5	<0.001	<0.001
Left eye SER	Observation period	Kruskal-Wallis	773.393	5	<0.001	<0.001

494 **Note:** Wilcoxon rank-sum test for two-group comparisons; Kruskal-Wallis H test for multi-group comparisons.

495

Table 6. Multivariable logistic regression for myopia

Table 6a. Myopia severity distribution in the grade-complete analysis subset

Note: This table includes 282,966 records with available grade (185,726 non-myopic; 97,240 myopic). Of 283,370 records, 404 with missing grade (320 non-myopic; 84 myopic) were excluded from this grade-complete subset. Full-sample severity counts are reported in Table 2.

Myopia severity	n (%)
Non-myopia	185,726 (65.6%)
Low myopia	53,906 (19.1%)
Moderate myopia	36,136 (12.8%)
High myopia	7,198 (2.5%)

Table 6b. Multivariable logistic regression

Variable	OR (95% CI)	P
Residence: Rural vs Urban	0.78 (0.76–0.79)	<0.001
Sex: Female vs Male	1.30 (1.27–1.32)	<0.001
Grade 2 vs Grade 1	2.62 (2.48–2.78)	<0.001
Grade 3 vs Grade 1	5.51 (5.22–5.81)	<0.001
Grade 4 vs Grade 1	10.95 (10.38–11.55)	<0.001
Grade 5 vs Grade 1	16.62 (15.77–17.52)	<0.001
Grade 6 vs Grade 1	23.06 (21.87–24.32)	<0.001
Grade 7 vs Grade 1	34.16 (32.37–36.07)	<0.001
Grade 8 vs Grade 1	37.22 (35.23–39.35)	<0.001
Grade 9 vs Grade 1	40.08 (37.87–42.44)	<0.001
Preschool vs Grade 1	1.35 (0.69–2.36)	0.342
Observation period (per 1 SD increase)	1.06 (1.05–1.07)	<0.001

Table 6c. Trend analysis for grade and myopia risk

Variable	Adjusted OR (95% CI)	Trend P	Non-linearity P
Per 1 grade increase	1.56 (1.55–1.57)	<0.001	<0.001

Table 6d. Effect sizes for SER by grouping variables

Outcome	Grouping	Effect size type	Value	Interpretation
Right eye SER	Residence	Rank-biserial r	0.123	Small

Left eye SER	Residence	Rank-biserial r	0.111	Small
Right eye SER	Sex	Rank-biserial r	0.041	Small
Left eye SER	Sex	Rank-biserial r	0.036	Small
Right eye SER	Grade	Kruskal-Wallis η^2	0.194	Large
Left eye SER	Grade	Kruskal-Wallis η^2	0.172	Large
Right eye SER	Observation period	Kruskal-Wallis η^2	0.003	Small
Left eye SER	Observation period	Kruskal-Wallis η^2	0.003	Small

Note: Trend model adjusted for residence, sex, year, and season; non-linearity test compares linear model with 3-df natural spline model. Rank-biserial correlation for two-group comparisons; Kruskal-Wallis η^2 for multi-group comparisons.

Table 7. Urban-rural × grade interaction and within-grade urban-rural differences

Grade	Urban: n; Prevalence	Rural: n; Prevalence	Adjusted OR (Urban vs Rural, 95% CI)	P
Preschool	99; 8.1%	86; 3.5%	2.34 (0.60–9.10)	0.221
Grade 1	24,858; 4.4%	15,005; 4.5%	1.00 (0.91–1.11)	0.934
Grade 2	23,208; 11.2%	14,419; 10.3%	1.12 (1.05–1.20)	0.001
Grade 3	22,556; 21.3%	13,930; 18.7%	1.19 (1.13–1.26)	<0.001
Grade 4	19,257; 35.3%	13,842; 30.3%	1.27 (1.21–1.33)	<0.001
Grade 5	18,266; 45.8%	13,874; 39.1%	1.33 (1.28–1.40)	<0.001
Grade 6	16,396; 54.6%	12,370; 46.5%	1.39 (1.32–1.45)	<0.001
Grade 7	3,482; 62.5%	26,717; 57.3%	1.26 (1.17–1.35)	<0.001
Grade 8	3,050; 68.7%	21,628; 58.6%	1.55 (1.42–1.68)	<0.001
Grade 9	1,546; 69.1%	18,377; 60.7%	1.51 (1.35–1.69)	<0.001

Note: Within-grade ORs from multivariable logistic regression with urban-rural × grade interaction, adjusted for sex and observation period; OR > 1 indicates higher urban myopia advantage within same grade.

Figure Legends

Figure 1. Comparison of overall and subgroup myopia prevalence among primary and secondary school students in Qujing, 2023-2025.

A, By sex; B, By urban-rural location; C, By left and right eye. Error bars represent Wilson 95% confidence intervals. Unilateral myopia defined as SER <= -0.50 D in that eye.

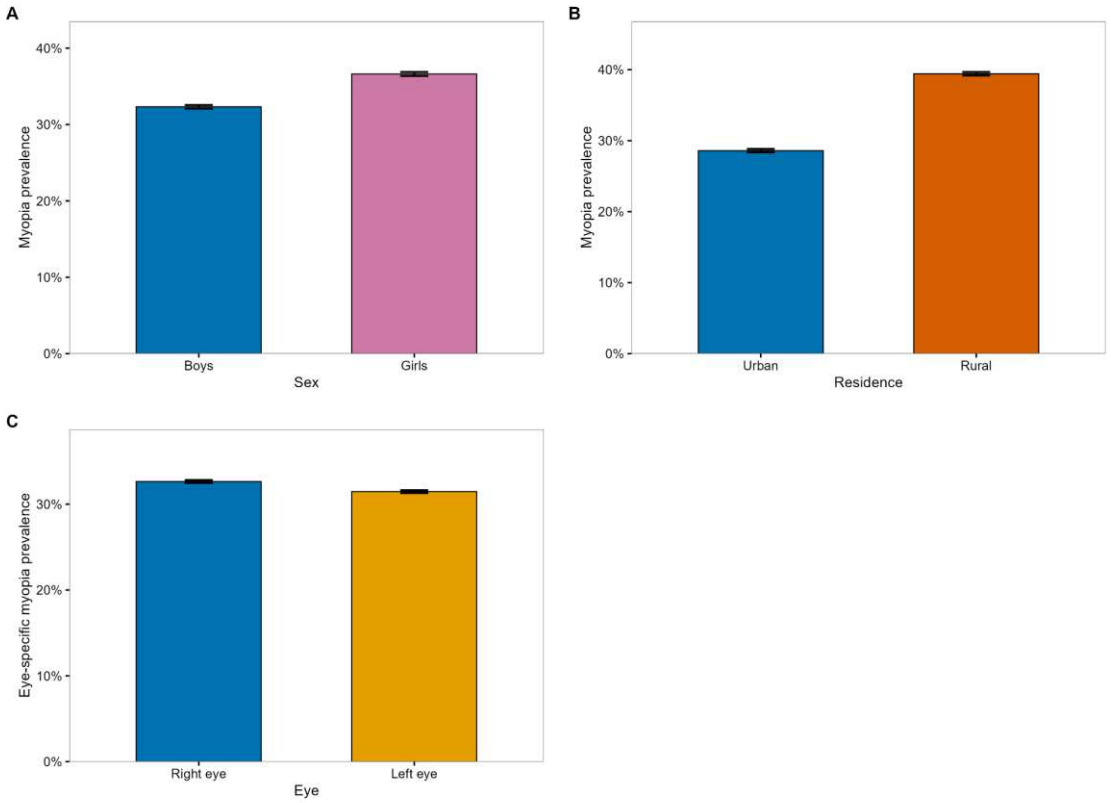
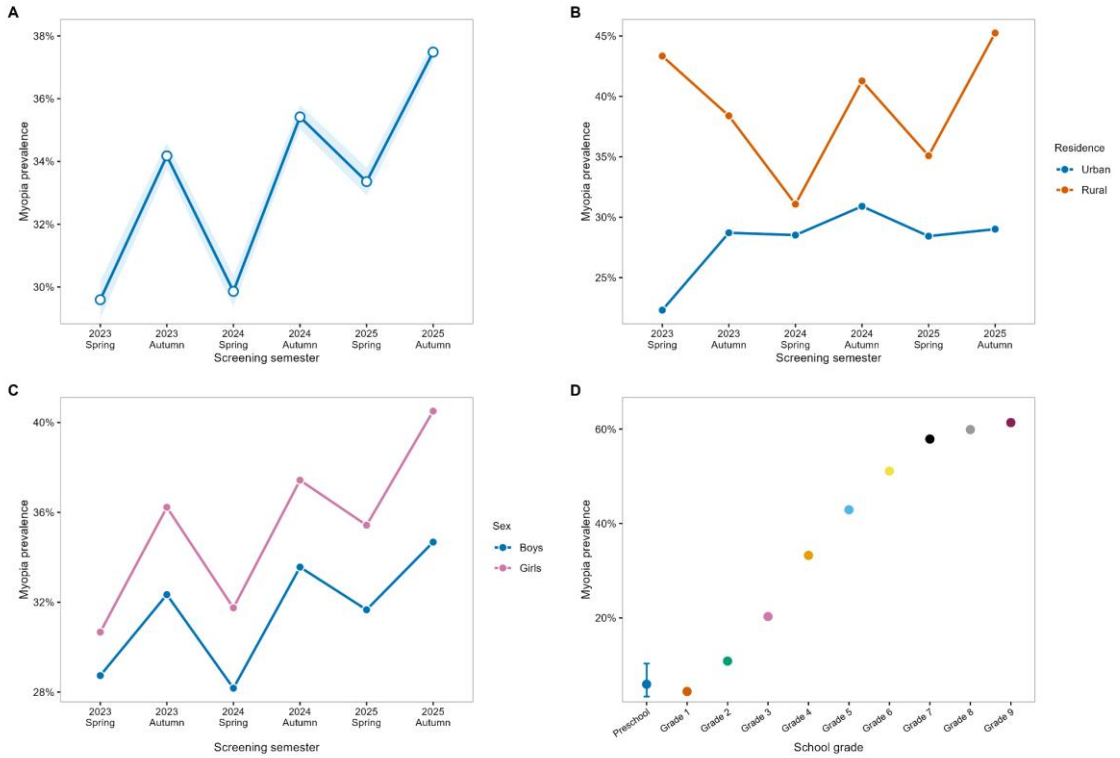


Figure 2. Overall and subgroup trends in myopia prevalence.

A, Overall myopia prevalence by observation period; B, Urban-rural myopia prevalence trends; C, Myopia prevalence trends by sex; D, Myopia prevalence and 95% confidence intervals by grade. Shading represents Wilson 95% confidence intervals.



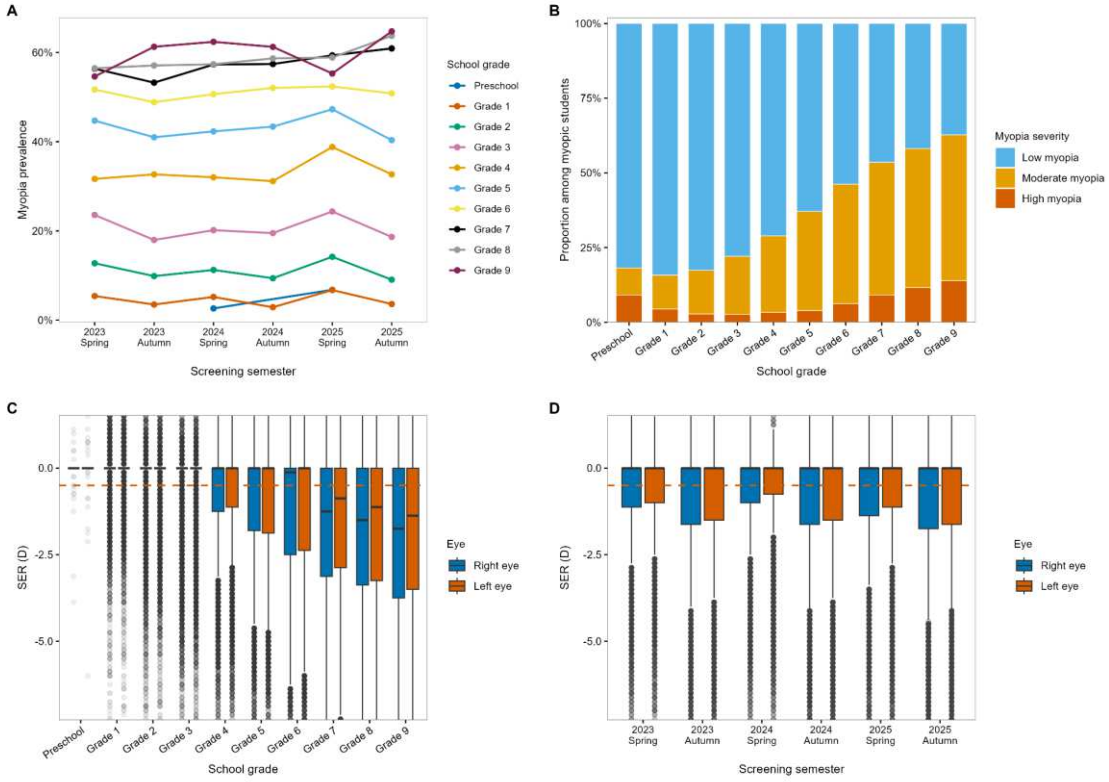
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523 **Figure 3. Grade differences and spherical equivalent refraction distribution.**

524 A, Myopia prevalence trends by grade; B, Myopia severity composition by grade among myopic students; C, Left-

525 and right-eye SER distribution by grade (box plots; orange dashed line indicates the -0.50 D threshold); D, Left-

526 and right-eye SER distribution by observation period.



527

528 **Figure 4. Extended analyses of temporal, sex, and high myopia patterns.**

529 A, Effects of year and spring/autumn season on myopia prevalence (adjusted for grade, urban-rural location, and

530 sex; year x season interaction $P < 0.001$); B, Sex x grade interaction (adjusted for urban-rural location and

531 observation period; interaction $P < 0.001$); C, Annual changes in urban-rural myopia disparity; D, High myopia

532 prevalence by grade (high myopia defined as worse-eye SER <= -6.00 D; error bars represent Wilson 95% CI).

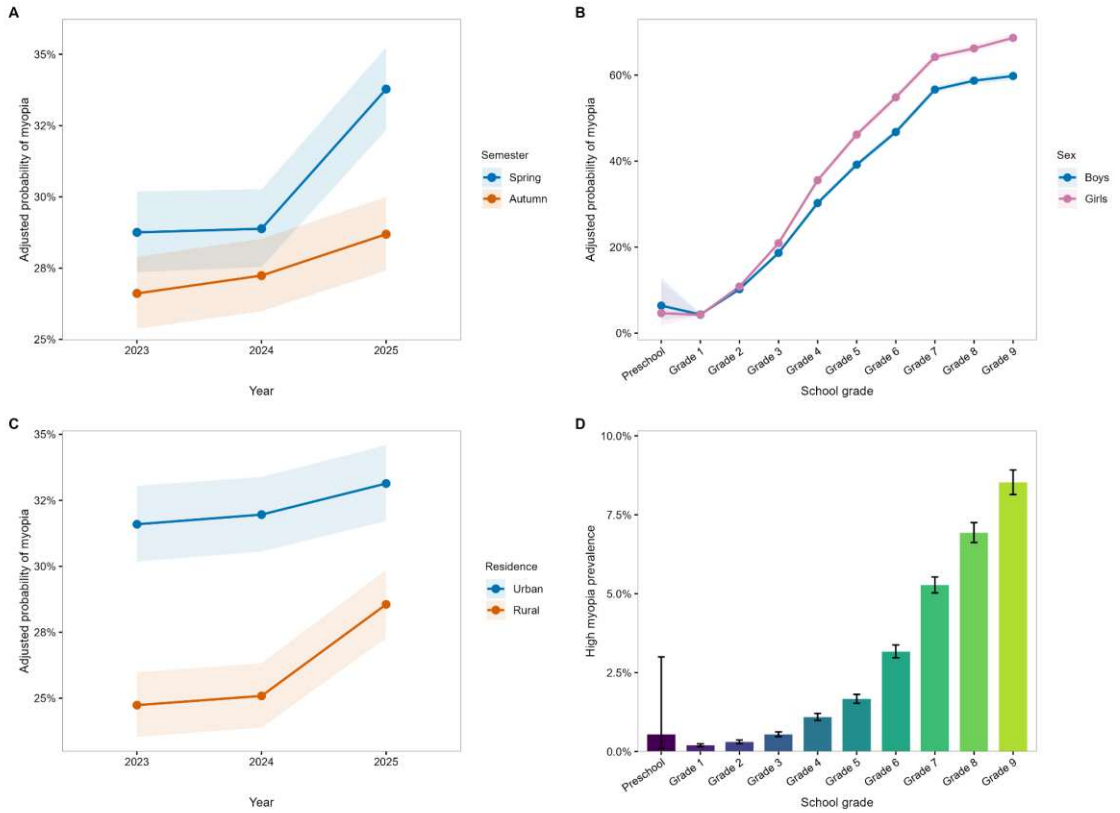


Figure 5. Urban-rural x grade interaction and spherical equivalent refraction distribution.

A, Model-adjusted myopia probability by grade for urban and rural students (adjusted for sex and observation period; interaction $P < 0.001$); B, Kernel density of left- and right-eye SER (orange dashed line indicates the -0.50 D threshold); C, Left- and right-eye SER correlation scatter plot (randomly subsampled to a maximum of 30,000 observations; black dashed line indicates the line of identity; orange dotted line indicates the -0.50 D threshold).

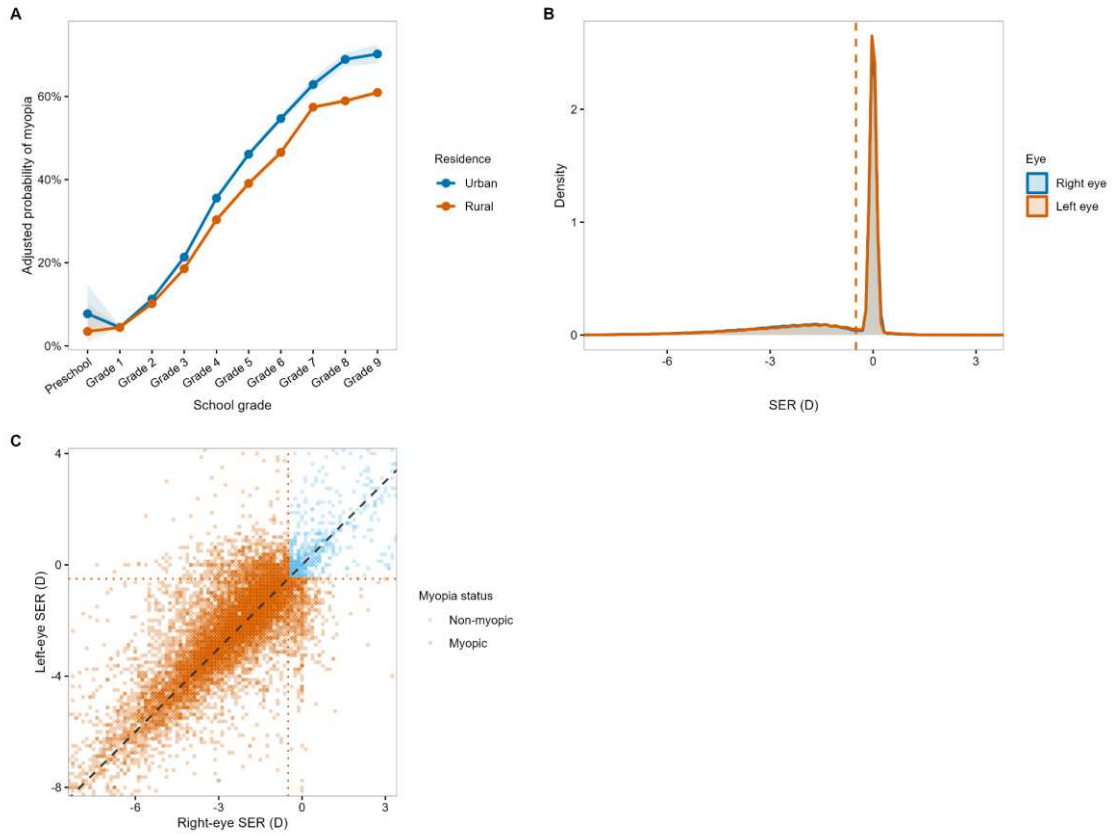


Figure 6. Bilateral myopia status and anisometropia.

A, Distribution of bilateral and unilateral myopia status; B, Anisometropia prevalence by grade (anisometropia defined as absolute inter-eye SER difference >= 1.00 D; shading represents Wilson 95% confidence interval).

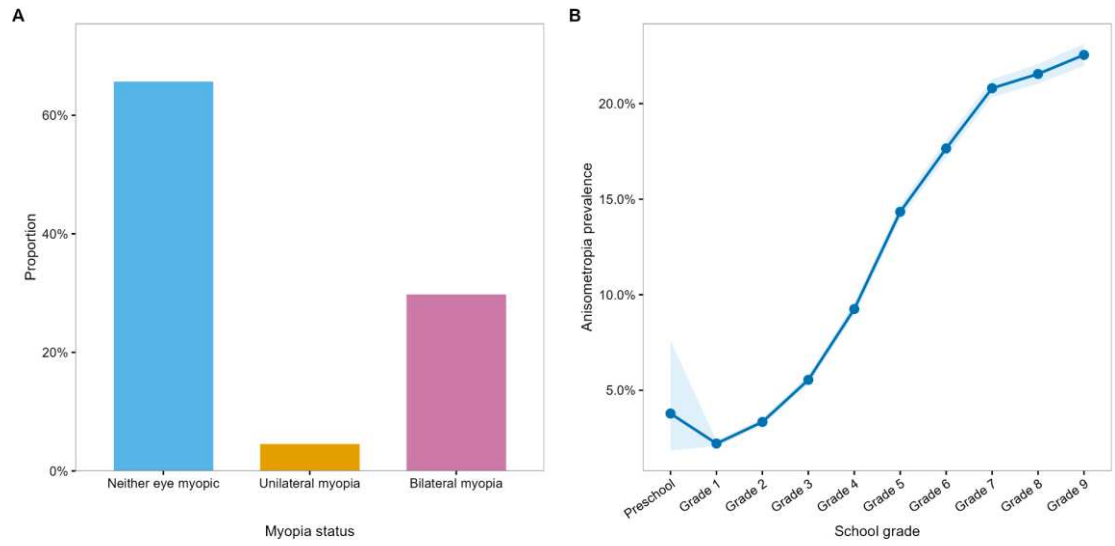
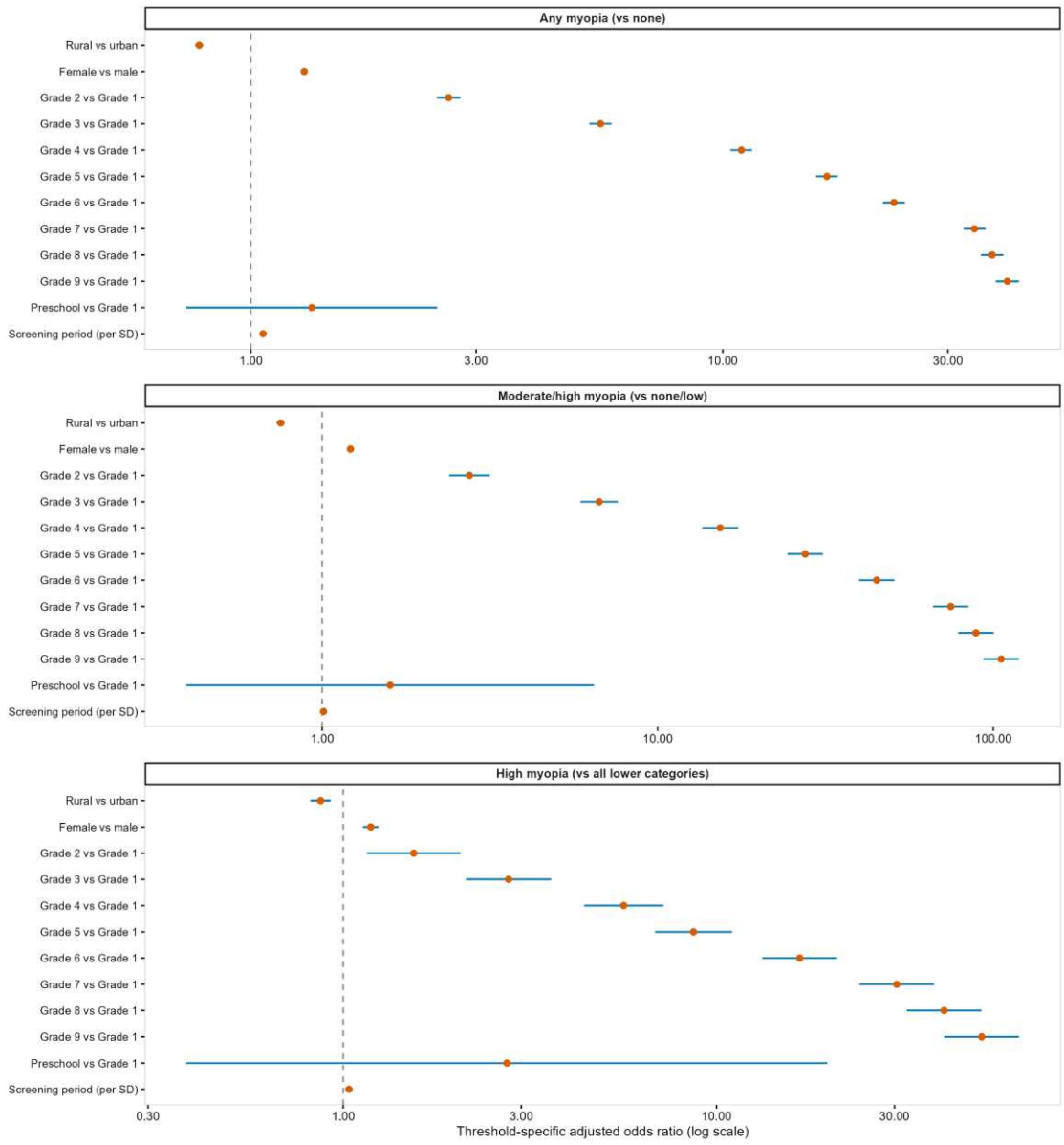


Figure 7. Threshold-specific logistic regression of factors associated with myopia severity.

Three adjusted binary logistic regression models compare any myopia versus none, moderate/high myopia versus none/low, and high myopia versus all lower categories. Points indicate adjusted odds ratios and horizontal bars 95% confidence intervals (logarithmic scale). The original proportional odds assumption was not satisfied ($P < 0.001$).



Supplementary Files

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- SupplementaryTables.docx