


The Impact of Sunshine Duration on Myopia in Central China: Insights from Populational and Spatial Analysis in Hubei

Runting Ma , Lianhong Zhou, Wenping Li, Yuanjin Li, Diewenjie Hu, Yi Lu, Cancan Zhang, Beixi Yi

Department of Ophthalmology, Renmin Hospital of Wuhan University, Wuhan, People's Republic of China

Correspondence: Lianhong Zhou, Department of Ophthalmology, Renmin Hospital of Wuhan University, No. 238 Jiefang Road, Wuhan, 430060, People's Republic of China, Tel +86 027-88041911-81219, Email zlh681102@aliyun.com

Purpose: This study aimed to analyze myopia distribution in Hubei and the impact of regional Sunshine Duration on myopia in children and adolescents.

Patients and Methods: The Cross-sectional study included students (kindergarten to grade 12) through multistage cluster stratified sampling in 17 cities (103 areas) of Hubei, China, who underwent ophthalmic examinations from September 2021 to November 2021. The association of sunshine duration with the prevalence and distribution of myopia was analyzed. Using Moran's index to quantify the distribution relationship, a spatial analysis was constructed.

Results: A total of 435,996 students (53.33% male; mean age, 12.16±3.74 years) were included in the study. A negative association was identified between myopia prevalence and sunshine duration in the region, especially in population of primary students ($r=-0.316$, $p<0.001$). Each 1-unit increment in the sunshine duration was associated with a decreased risk of myopia prevalence (OR=0.996; 95% CI, 0.995–0.998; $P<0.001$). Regression showed a linear relationship between sunshine duration and myopia rates of primary school students [Prevalence%= $(-0.1331*\text{sunshine duration}+47.73)\%$, $p=0.02$]. Sunshine duration influenced the distribution of myopia rates among primary (Moran's $I=-0.206$, $p<0.001$) and junior high school (Moran's $I=-0.183$, $p=0.002$). Local spatial analysis showed that areas with low sunshine duration had high myopia prevalence concentration.

Conclusion: This study revealed sunshine duration associations with myopia prevalence at the regional and population levels. The results may emphasize the significance of promptly implementing myopia control in regions with poor sunshine. The effect of sunshine on myopia is pronounced in the early years of education, especially in primary students.

Keywords: myopia, sunshine duration, children, Spatial Analysis, Moran's Index, epidemiology

Introduction

Myopia has emerged as a significant global health concern, particularly in regions like East Asia, where myopia rates have soared beyond 80% in some areas.^{1–3} In China, this issue has escalated into a critical public health challenge, posing a threat to the vision of children and adolescents.^{4,5} The progression of myopia may culminate in high myopia over time, elevating the risk of debilitating eye complications.⁶ The contemporary shift in technology and lifestyle patterns has precipitated environmental changes that accelerate the onset of myopia. Factors such as increased use of electronic devices, artificial lighting, reduced outdoor activities, and early initiation of preschool education have expedited the process of emmetropization.² The etiology of myopia is multifaceted, with research indicating that intermediate and distal factors play pivotal roles. Studies have underscored the significance of inadequate outdoor exposure,^{7–9} alterations in lighting conditions,^{10,11} escalating urbanization,¹² and educational pressures^{13,14} in shaping the onset and progression of myopia. Multiple factors may be intertwined with light exposure or sunshine to varying extents.

Over the past two decades, the protective role of outdoor activity against myopia has garnered increasing support. Research indicates that outdoor activity diminishes the likelihood of inheriting parental myopia and reduces the risk

associated with prolonged close-distance eye use.^{15,16} Meta-analyses have further substantiated these findings, demonstrating that each additional hour of outdoor time per week correlates with a 2% decrease in myopia risk.¹⁷ Extensive research has highlighted light exposure as a potential mechanism through which outdoor activity mitigates myopia. Animal studies involving chicks and rhesus monkeys have elucidated the inhibitory effect of bright light on form-deprivation myopia, a process intricately linked with dopamine receptors.^{18,19} Notably, sunlight emerges as the paramount light source in daily life, with its conditions inherently linked to outdoor activity. A study by Cui et al on Danish children revealed that increased exposure to sunlight restrained axial length growth and myopia development.²⁰ Given the natural variability in sunlight conditions attributable to geographical factors, differences in myopia prevalence across regions become apparent. Research spanning four provinces and cities in China observed correlations between myopia rates and regional geographical characteristics. Latitude and longitude were found to correlate with sunlight intensity, while regional temperature influenced outdoor activity patterns.²¹

Epidemiological studies leveraging data from the natural environment offer valuable insights into diseases and associated risks, facilitating a comprehensive understanding of health trends. With the advancement of spatial epidemiology, researchers can now effectively characterize disease distributions within larger populations.^{22,23} Global Moran's I is a statistical index invented by Moran to capture spatial autocorrelation. Briefly, spatial autocorrelation is used to show that there is a certain distribution pattern and correlation of similar phenomena in adjacent areas. For example, the onset of diabetes is related to economy, and the Index can demonstrate that affluent areas tend to have a high prevalence, from a spatial perspective.²⁴ The advantage is that environmental influences are hypothesized in spatial level, rather than just from the traditional population perspective.

In myopia research, investigations have revealed regional clustering patterns in myopia prevalence across China between 2005 and 2014. Moreover, these clustering hotspots have demonstrated dynamic shifts correlating with social development.²⁵ Building upon this framework, considering regional and population dimensions, our study explores the relationship between sunlight exposure and myopia prevalence. We aim to elucidate this association's correlative and spatial links, enhancing our understanding of myopia epidemiology and sunlight exposure.

Materials and Methods

Survey Area

Hubei is located in central China (latitude 29°01'53"-33°6'47"N, longitude 108°21'42"-116°07'50"E). Hubei has subtropical monsoon weather, with prominent north-south transitional climate characteristics. The geographical conditions of Hubei are distinctly divided, with the west belonging to the mountainous, hilly area and the east gradually transforming into the plain. Hubei province has 17 cities and 103 county-level administrative units (counties, county-level cities, and districts) under its jurisdiction (Figure 1).

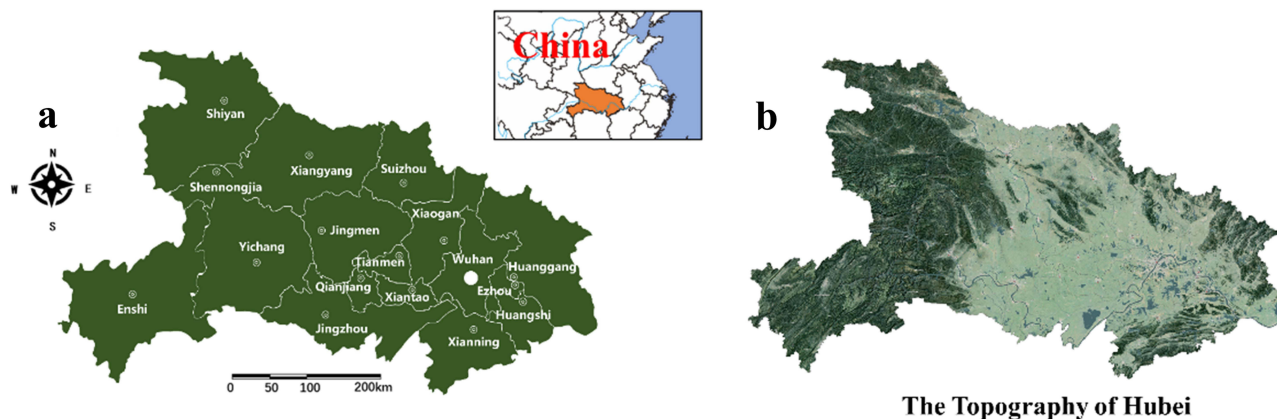


Figure 1 Map of Hubei Province. (a) Administrative Divisions; (b) Geographical Features.

Study Population

Ethical approval for the study was obtained from the Ethics Committee of Renmin Hospital of Wuhan University. Cross-sectional survey. Each county-level administrative region is a survey site covering all 103 sites. Based on the principles of sample size calculation ($N = u^2 \times p(1-p)/d^2$), we determined the number of people to be sampled at each survey site. N = sample size; p = prevalence estimate; d = permissible error, $d = 0.04p$; α is Type I error, With a 95% confidence level ($\alpha = 0.05$), $u_{\alpha} = 1.96$. According to National Health Commission data, the myopia rate in mainland China among children and adolescents is approximately 52.7% (p). $N = 1.96 \times 0.527 \times (1 - 0.527) / (0.04 \times 0.527)^2 \approx 2154$.

Considering potential absences and refusals, each survey site should include >2200 students aged 6~18. All survey sites successfully enrolled participants, meeting the minimum sample size (Figure S1). Multistage cluster stratified sampling was used for the study (Figure S2).

Ocular Examination

Visual acuity was measured at an examination distance of 5m using the Unified Standard Logarithmic Visual Acuity Scale (GB11533). For those who wore glasses, UCVA and corrected VA were examined separately. VA was measured and finally recorded in logMAR. The teacher instructed all students before the examination and ensured they could recognize the vision charts correctly. All participants underwent non-cycloplegic autorefraction (ISO10342), expressed in spherical equivalent refraction (SER). Each SER was obtained by taking the average of three measurements. Myopia is diagnosed if at least one eye has poor visual acuity ($\log\text{MAR} > 0.0$) and $\text{SER} \leq -0.50$ D. Orthokeratology users are also considered myopic. Classification of myopia is defined as two types: low to moderate myopia ($\text{SER} \leq -0.5$ D and > -6.0 D) and high myopia ($\text{SER} \leq -6.0$ D).

Inclusion and Exclusion

Inclusion: I. Students aged 6–18 years; II. Understanding and willing to participate in eye examinations; III. Permanent residents of the survey area. Exclusion: I. Unable to cooperate with the eye examination; II. Children with organic eye pathology; III. Significant refractive interstitial abnormalities; IV. Those who failed quality control after multiple measurements.

Quality Control

All medical staff were uniformly trained to perform the procedure, and professional ophthalmologists carried out all processes. If the difference between two results for one eye of the subject is higher than $0.5D(\text{SER})/0.1(\text{LogMAR})$, the result is automatically invalidated and re-measured. Results are uploaded to a cloud-based system in real-time, ensuring data integrity. Random retesting of at least 5% of participants is conducted, and if the retest error rate exceeds 10%, all data from the respective school are invalidated on the same day.

Sunshine Duration and Geographical Data

Sunshine duration represents the duration of direct sunlight from sunrise to sunset ($>120 \text{ W/m}^2$), unaffected by shading (clouds, fog), measured in hours. Sunshine duration data is obtained from the China Meteorological Data Sharing Service (<http://Data.cma.cn/>). The average monthly sunshine duration for the 103 areas was calculated using data from 2018–2020. Geographical and social data (longitude, latitude, temperature, altitude, precipitation, GDP per capita) were sourced from the Hubei Provincial Bureau of Statistics (<https://tjj.hubei.gov.cn/>) (Table S1). The sunshine duration was recorded in hours/month. With seasonal changes, the number of sunshine displays relatively obvious seasonal differences. It shows the characteristics of high in summer (May to Jul, 148.44 hr/m) and fall (Aug. to Oct, 166.67 hr/m), and low in spring (Feb. to Apr, 125.62 hr/m) and winter (Nov. to Jan, 108.02hr/m). However, in general, the annual variation of monthly sunshine duration in Hubei Province is steady, basically ranging between 128 to 140 hr/m. Based on data from the Hubei Meteorological Bureau (<http://hb.cma.gov.cn/>). Hubei had an average sunshine duration of approximately 135hr/m in 2020, categorizing the 103 areas into ≥ 135 hr/m and < 135 hr/m groups, reflecting different sunshine conditions (Figure S3 in supplementary file).

Statistical Analysis

Statistical analysis was performed using SPSS 22.0 and Geoda 20.0. The prevalence of myopia was expressed as rate (%), and count data were expressed as mean \pm standard deviation. Myopia rates of different subgroups were compared using the chi-square test. Comparison of spherical equivalent refraction or sunshine duration was conducted by ANOVA or *t*-test. Logistic regression was used to analyze the risk of myopia from different influences. Linear regression and Pearson's test were used to analyze the correlation between sunshine duration and regional myopia prevalence. Moran's index was used to characterize the spatial distribution between myopia and sunshine duration at the spatial level. Map vectors were downloaded from DataV GeoAtlas (<http://datav.aliyun.com/>). All tests were performed using a two-sided test with a significance level of 0.05.

Spatial Analysis

Results are more similar between spatially close regions, reflecting location dependence on attribute values.²⁶ The analysis is conducted from global and local perspectives. Global Moran's I could measure myopia distribution and sunshine duration aggregation, with values ranging from -1 to 1 , suggesting aggregation when $p < 0.05$.²⁷ For example, when the global Moran Index = 1 , it represents the largest positive association. That means the area have high sunshine duration, also high myopia prevalence. Conversely, when the index = -1 , it represents the largest negative association. The zero value indicates a random spatial pattern in which sunshine does not influence regional prevalence. Ideally, we would like the Moran index between myopia and sunshine to be less than 0 , which means that good sunshine conditions are accompanied by low rates of myopia.

The above analysis is macroscopic, and it could give an idea of whether sunlight is associated with myopia rates in an area. However, it could not clearly indicate which area has the most pronounced association with sunlight. Hence, we used Local Indicator of Spatial Association (LISA) further explores spatial clusters and outliers.²⁸ Results classify spatial relationships into four types:²⁸ high-high (hot spots), low-low (cold spots), high-low (high-low), and low-high (low-high). For instance, a High-Low spot in Map (red parts in Figure 6) signifies high sunshine duration with a concentration of low myopia rates.

The spatial analysis was conducted in Geoda 1.20. After importing map data (shp file), myopia data, and geographic information (excel file) into Geoda, create spatial weights of the map and select Queen contiguity. Calculate Moran's index and create visual maps using the global and local modes in the spatial analysis function. The number of Monte Carlo randomizations was 999.

Results

A total of 489,257 students were invited to partake in the study, of which 435,996 students, spanning from kindergarten through senior high school, passed the quality control criteria and actively participated (participation rate: 89.9%). The students' mean (standard deviation) age was 12.16 (3.74) years. 53.33% were male and 46.67% were female. The study sample reasonably covered all grades in kindergarten (24,461), elementary school (195,476), junior high school (100,068), and senior high school (115,791) (Table S2). Myopia prevalence (7.85% to 82.72%) and myopia severity (0.17D to -3.26 D) tend to increase progressively with grade level (Figure S4).

Hubei Province is divided into four major regions (Table S3). Myopia rates in Hubei exhibit notable regional disparities, with higher rates observed in the western parts of the region (Figure 2). Specifically, the myopia prevalences (95% CI) in Northeast, Southeast, Northwest, and Southwest Hubei were 46.36% (46.0%-46.5%), 48.25% (47.9%-48.6%), 55.98% (55.7%-56.3%), and 52.71% (52.3%-53.1%), respectively (Table 1). Similarly, significant variations in regional sunshine durations were observed. The average sunshine duration in Northeast, Southeast, Northwest, and Southwest Hubei was 140.82 ± 12.42 , 130.93 ± 10.21 , 134.88 ± 11.32 , and 115.76 ± 9.82 hours per month, respectively. These findings suggest that differences in sunshine duration across regions may influence the distribution of myopia prevalence.

We stratified students into two groups based on sunshine duration, ranging from 91.2 to 147.8hr/m. The overall average sunshine duration in Hubei was found to be 135hr/m. These groups were categorized as high sunshine (sunshine duration ≥ 135 hr/m) and low sunshine (sunshine duration < 135 hr/m) areas. The prevalence of myopia among students

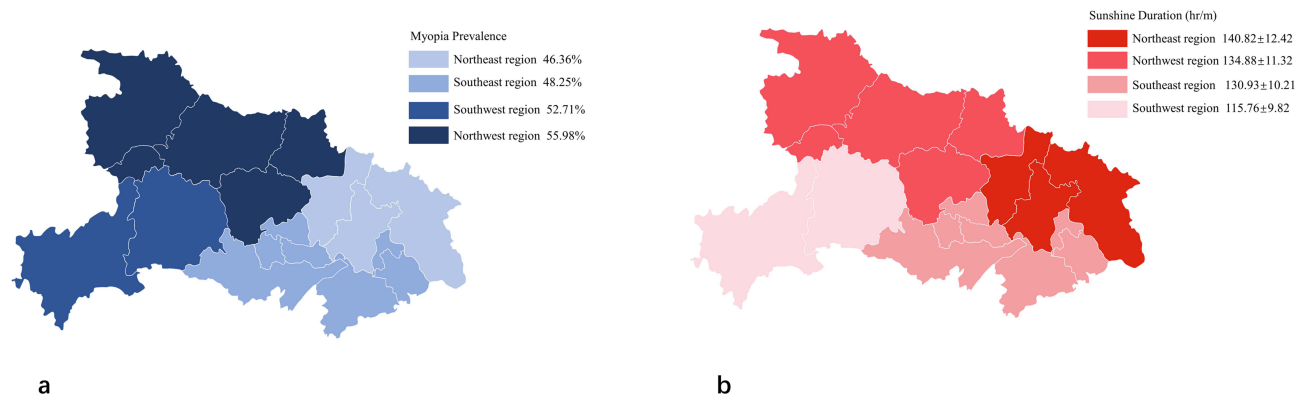


Figure 2 Distribution map of myopia prevalence and sunshine duration in Hubei. (a) prevalence; (b) sunshine duration.

residing in high sunshine areas was 48.6%, while in low sunshine areas, the prevalence slightly increased to 52.6%. Conversely, areas with high sunshine have less myopia ($-1.52 \pm 2.09D$ vs $-1.66 \pm 2.18D$) (Table 2). In short, areas with good sunlight have higher prevalences of myopia. At the same time, more people with myopia live in areas with insufficient sunshine (Figure 3).

To analyze the variables influencing myopia development, various factors, including sunshine duration, social and educational factors, and geographic and personal variables, were compared between myopic and non-myopic individuals. Statistical analysis revealed significant differences in age, gender, grade, SER, GDP per capita, type of residence, longitude, latitude, altitude, temperature, precipitation, and sunshine duration between the two groups (Table S4).

Further investigation into the association between sunshine duration and myopia was conducted using the logistic regression models, adjusting for potential confounding variables such as age, gender, grade, GDP per capita, type of residence, longitude, latitude, altitude, temperature, and precipitation. The results indicated a significant association between elevated sunshine duration and a decreased risk of myopia (Table 3). For each 1-unit increment in the sunshine duration, there was a 0.4% decreased risk of myopia (OR=0.996; 95% CI 0.995–0.998; $P < 0.001$), particularly noticeable in the primary and kindergarten students. Correlation and regression analyses further corroborated these findings, particularly emphasizing the impact on the primary student population. Pearson correlation coefficient revealed a negative correlation between sunshine duration and myopia prevalence among primary students ($r = -0.229$, $p = 0.020$), indicating that regions with higher sunshine duration exhibited lower myopia prevalence. In contrast, the sunshine duration was positively correlated with the SER of primary students ($r = 0.212$, $p = 0.032$). The correlation analysis between kindergarten, middle school and high school and sunlight was not significant. Regression analysis demonstrated a linear relationship between sunshine duration and myopia among primary students (Figure 4), with each unit increase in sunshine duration associated with a reduction in prevalence [prevalence% = $(-0.1331 * \text{sunshine duration} + 47.73)$ %, $p = 0.020$]. Similarly, each unit increase in sunshine duration associated with a reduction in severity of myopia in primary students [SER = $(0.0003567 * \text{sunshine duration} - 1.118)$, $p = 0.0318$]. These consistent trends

Table 1 Differences of Distribution in Myopia Prevalence and Sunshine Duration

Areas	Sample/N	Myopia prevalence (95% CI)	Sunshine duration (hr/m)
Northeast	152,481	46.36% (46.0%-46.5%)	140.82±12.42
Southeast	92,837	48.25% (47.9%-48.6%)	130.93±10.21
Northwest	119,417	55.98% (55.7%-56.3%)	134.88±11.32
Southwest	71,264	52.71% (52.3%-53.1%)	115.76±9.82
P value ^a		<0.001	<0.001

Notes: ^a χ^2 -test was used for categorical variables, and a *t*-test was used for continuous variables; CI, confidence interval.

Table 2 Comparison of Myopia Prevalences and Severity Under Different Sunlight Conditions

Sunshine duration	Sample/N	Myopia prevalence (95% CI)	Mean SER / D
≥135hr/ m ^a	238,452	48.6% (48.4%-48.8%)	-1.52±2.09
<135hr/m	197,544	52.6% (52.4%-52.9%)	-1.66±2.18
P value ^b		<0.001	<0.001

Notes: ^a Average sunshine duration of Hubei Province: 135hr/m; ^b χ^2 -test was used For categorical variables, and a t-test was used for continuous variables.CI, confidence interval.

underscore the association between sunshine conditions and regional myopia prevalence, highlighting the potential importance of sunshine condition in mitigating myopia risk.

The study conducted a comparison of myopia prevalence among subgroups across all grades (kindergarten-grade 12) in areas characterized by high sunshine (≥135 hours per month) versus low sunshine (<135 hours per month). Overall, children residing in areas with low sunshine exhibited a higher prevalence of myopia than those in high sunshine areas (52.6% vs 48.6%, $p<0.001$). Moreover, when analyzing grade-level subgroups, significant differences in myopia prevalence and SER were observed (Table 4). Specifically, children in grades 1–7 showed lower rates of myopia in high sunshine areas compared to their counterparts in low sunshine areas ($p<0.001$). The severity of myopia showed the parallel phenomenon. However, as grades progressed and educational burdens increased, the disparity in myopia prevalence and SER between high and low sunshine areas diminished. This suggests a potential weakening of the protective effect of sunshine with increasing grades and educational workload (Figure 5).

The study conducted spatial analyses to explore the statistical significance of the association and distribution characteristics between myopia prevalence and sunshine duration. The global bivariate Moran index was utilized as an indicator to assess the overall relationship between the two distributions. Results indicated that the distribution pattern of myopia, particularly among primary students (Moran’s $I=-0.206$, $p<0.001$) and junior high school students (Moran’s $I=-0.183$, $p=0.002$) in Hubei, was non-random and influenced by the distribution of sunshine (Table 5).

Furthermore, local spatial analysis using LISA maps identified specific regions where the effect of sunshine duration on myopia distribution was observed. These maps visualized the spatial relationship across 103 regions, revealing that areas with low sunshine duration tended to cluster areas with high myopia prevalence concentrations (Figure 6). The LISA map illustrates that “low-high” points are primarily concentrated in the suburbs of Wuhan, Huanggang, and Huangshi, indicating relatively low myopia rates and higher sunshine duration in the eastern regions. Conversely, “high-low” points are predominantly concentrated in Enshi, Yichang, and Shiyan, indicating relatively high myopia rates and lower sunshine duration in the western regions. This distribution pattern is particularly evident in primary and junior high

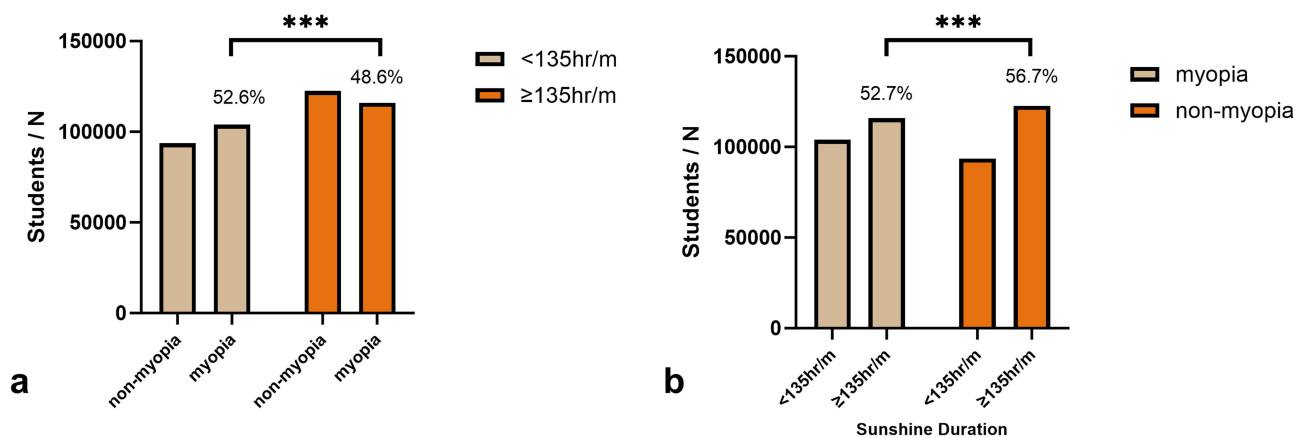


Figure 3 Myopia prevalence by low and High sunshine duration. (a) comparison of prevalence under different sunshine condition; (b) comparison of sunshine condition under different refraction modes; χ^2 -test was used for categorical variables; *** $p<0.001$.

Table 3 Associations Between Sunshine Duration and the Prevalence in Different Education

Groups	Sunshine duration	
	OR (95% CI)	P value
Prevalence of kindergarten ^a	0.992 (0.988–0.997)	0.002
Prevalence of primary school ^a	0.992 (0.991–0.994)	<0.001
Prevalence of junior high school ^a	0.997 (0.995–0.998)	<0.001
Prevalence of senior high school ^a	0.998 (0.996–0.999)	<0.001
Prevalence in total ^a	0.996 (0.995–0.998)	<0.001

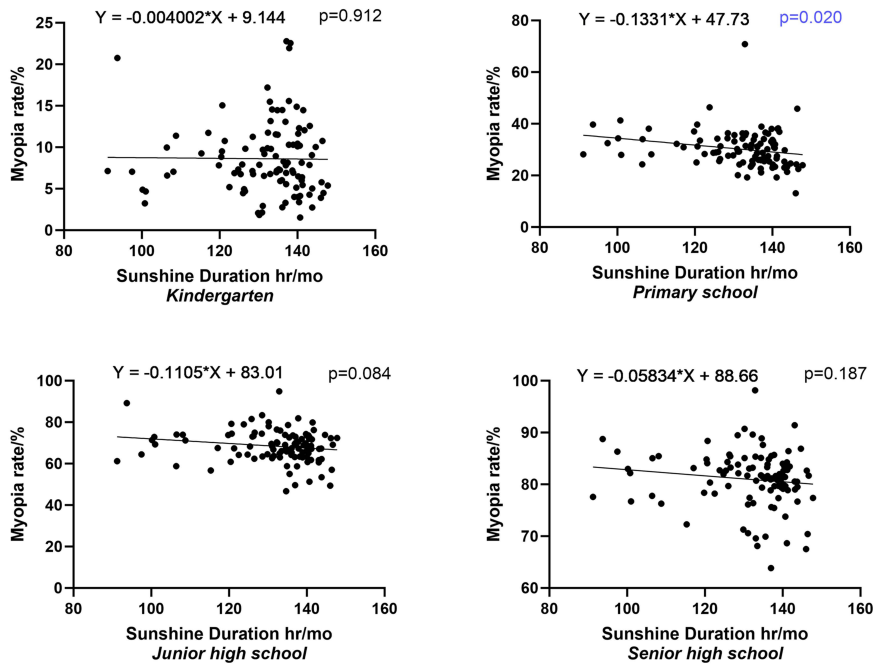
Notes: ^a logistic regression adjusted for age, gender, grade, GDP per capita, type of residence, longitude, altitude, temperature, and precipitation; CI, confidence interval.

school analysis maps. In contrast, most areas of the LISA maps for kindergarten and high school do not reflect a marked pattern of correspondence. To further understand the relevant factors and distribution characteristics of sunshine duration in Hubei, differences in sunshine duration were analyzed after grouping using various geographical indicators. Findings indicated that longitude, altitude, and precipitation influenced sunshine duration. Generally, eastern regions exhibited higher sunshine duration compared to western regions. Additionally, areas with higher precipitation tended to have lower sunshine duration. Furthermore, plains typically demonstrated higher sunshine duration, while hilly areas exhibited lower sunshine duration (Table S5). Global spatial analysis also affirmed the impact of these geographical factors on sunshine duration distribution (Table S6).

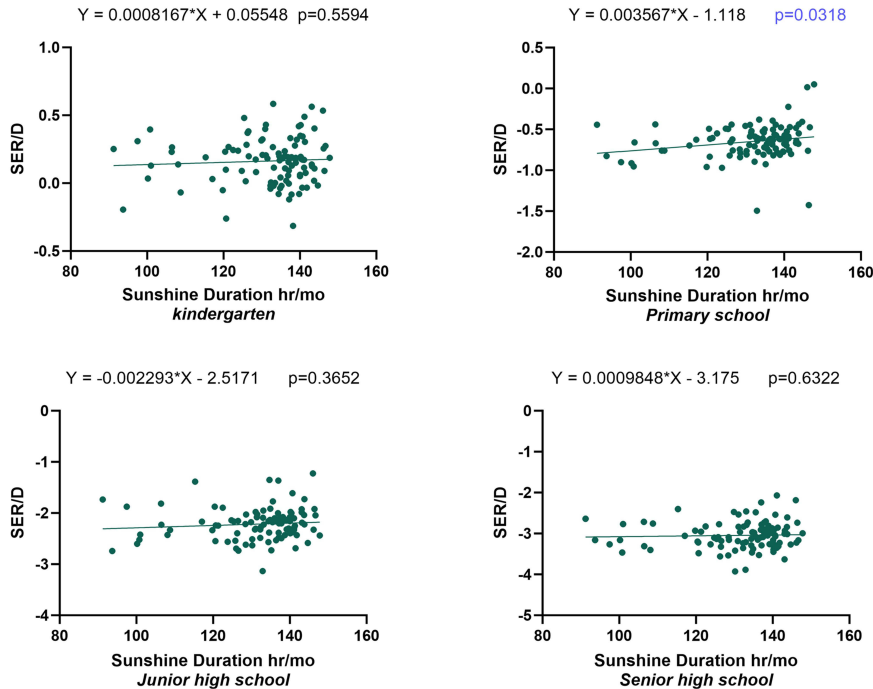
Discussion

The global prevalence of myopia is undergoing a rapid increase, with projections estimating that by 2050, there will be 4.758 billion myopic individuals worldwide, constituting 49.8% of the total population.²⁹ In our previous study conducted in 2019,³⁰ we focused on elementary students (grades 1–3) and utilized machine learning alongside questionnaires to identify high-risk groups for myopia progression whose results inspired us the importance of myopia management in younger students. As we continued our routine work, we uncovered significant regional differences in myopia rates within Hubei. To explain this phenomenon, this urgently requires a new work with spatial epidemiology to analyze. The present study is a new large-sample cross-sectional analysis conducted in 2021. We expanded range of subjects (kindergarten- grade 12) and the sample size is tens of times larger than before. The students in the former will not be selected. Our aim was to elucidate the distribution pattern of myopia rates from a novel perspective, particularly considering the impact of sunshine and the macro-natural environment, which has not been done before. By combining large-scale samples with environmental data, a new perspective emerges on understanding the influence of sunshine on regional myopia. Our study initially highlights regional disparities in sunshine conditions within Hubei. Given Hubei's diverse geographic features, these differences likely extend to variations in natural environments and sunshine conditions across regions. Our findings indicate lower sunshine in the Western region and higher sunshine in the Eastern part of Hubei. Additionally, disparities in myopia prevalences among students aged 6–18 years are evident across regions, with higher rates in the west and lower rates in the east. A preliminary comparison underscores regions with lower sunshine exhibit relatively high myopia prevalence, reaching 52.6%. Conversely, areas with high sunshine, mainly in the eastern part of Hubei, demonstrate relatively low myopia rates of 48.6%. The relationship between sunshine and myopia is not entirely consistent and linear because of the complexity of factors that influence myopia. For example, the Northwest area does not have the least sunshine, but it has the highest myopia prevalence. However, the general trend that regions with higher sunshine have relatively lower myopia prevalence has been demonstrated, at least in the distributional trends.

We conducted correlation and regression analyses to delve deeper into the correlation between sunshine and myopia prevalence. Initially, our findings revealed a negative correlation between myopia prevalence among primary students and sunshine duration. Subsequently, upon adjusting for confounding factors such as gender, grade, and age, we discovered that sunshine duration exerted a protective effect on myopia (OR = 0.996; 95% CI, 0.995–0.998; P <



a



b

Figure 4 Linear regression analysis of regional myopia prevalences/SER and sunshine duration. **(a)** prevalence- sunshine duration; **(b)** SER- sunshine duration; Scatter plots represent myopia prevalences/SER in relation to sunshine duration for 103 areas; The straight line is the trend line proposed for the regression analysis; The upper equation is the regression equation.

Table 4 Myopia Prevalence by Grade Under Different Sunlight Conditions

Grade	Sample/N	Prevalence/%		P value ^b	Mean SER/D		P value ^b
		≥135hr/m	<135hr/m		≥135hr/m	<135hr/m	
0 ^a	24,661	7.6	8.1	0.233	0.185	0.174	0.373
1	31,380	4.2	7.3	<0.001	0.170	0.103	<0.001
2	30,735	12.1	14.0	<0.001	-0.109	-0.138	<0.001
3	32,722	22.4	24.2	<0.001	-0.391	-0.427	<0.001
4	33,169	31.6	34.6	<0.001	-0.735	-0.794	<0.001
5	33,107	43.5	45.5	<0.001	-1.031	-1.082	0.004
6	34,363	50.6	52.7	<0.001	-1.354	-1.427	<0.001
7	34,526	59.9	61.6	<0.001	-1.830	-1.879	0.016
8	32,986	68.2	68.6	0.395	-2.175	-2.225	0.025
9	32,556	74.5	75.4	0.060	-2.554	-2.556	0.948
10	43,083	77.7	78.1	0.391	-2.864	-2.853	0.606
11	40,037	81.9	82.2	0.369	-3.033	-3.057	0.732
12	32,671	82.5	83.0	0.228	-3.271	-3.257	0.582
Total	435,969	48.6	52.6	<0.001	-1.520	-1.662	<0.001

Notes: ^a kindergarten (preschool stage) =grade 0; ^b For categorical variables, a χ^2 -test was used. For continuous variables, a t-test was used.

0.001), particularly among primary and kindergarten students (OR = 0.992). Moreover, linear regression analysis further supported these observations. These statistical findings may underscore the role of sunshine as a protective factor against myopia, particularly in the primary school-age population.

Notably, elementary school children represent a critical period characterized by the rapid development and escalation of myopia rates. Building upon these findings, our study stratified students by grade and compared myopia prevalences across varying sunshine conditions. The outcomes underscored significant disparities in myopia rates between grade 1 and grade 7, gradually converging as educational years progressed. During childhood, eyes typically tend toward hyperopia, with the spherical equivalent refraction diminishing over time. However, empirical evidence indicates that many children attain emmetropia earlier and are susceptible to myopia during the primary school years. Research suggests that outdoor activities can be a preventive measure against myopia onset and significantly delay axial length growth in non-myopic children.⁷ While the analysis for kindergarteners was not fully significant in statistic, this may not mean that they are unaffected by sunshine. The kindergarteners are at critical stage of emmetropization, and comparison of prevalence may not adequately represent differences in the speed of emmetropization. In the future, longitudinal comparisons of refractive development data may be necessary to explain this phenomenon. Our findings may underscore the protective effect of sunshine conditions before the completion of emmetropization. This highlights a critical window for myopia prevention interventions and outdoor activities. Enhancing outdoor activity and fostering sunlight exposure

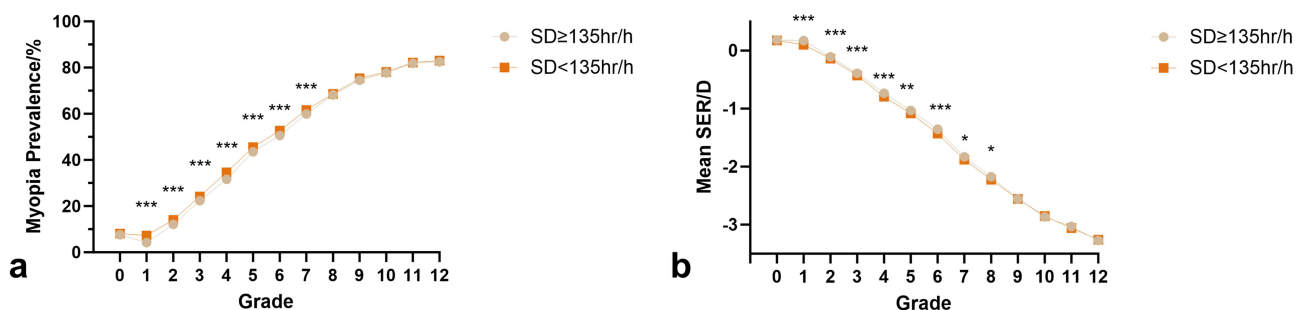


Figure 5 Comparison of myopia prevalence and severity by grade under different sunlight conditions. **(a) Prevalence:** The brown line is consistently under the Orange line in grades 1–7; **(b) Severity:** The Orange line is consistently under the brown line in grades 1–8; The brown line represents students living in high sunshine conditions (≥135hr/m), and the Orange line represents children living in low sunshine (<135hr/m); For continuous variables, a t-test was used; * p<0.05, **p<0.01, ***p<0.001.

Table 5 Global Spatial Analysis of Myopia Rates and Sunshine Duration

Distribution (prevalence- sunshine duration)	Global bivariate Moran's I	Z	P value ^a
Myopia of kindergarten ^a	0.021	0.390	0.366
Myopia of primary school ^a	-0.206	-3.927	<0.001
Myopia of junior high school ^a	-0.183	-3.158	0.002
Myopia of senior high school ^a	-0.050	-0.258	0.532

Notes: ^a P values were calculated using the Z test.

may be imperative, particularly in regions with inadequate sunlight. These interventions promise to mitigate myopia progression and promote ocular health among school-aged children.

The myopia arises from a complex interplay of polygenic factors and various environmental influences, making it challenging to attribute to a single cause. Despite extensive research on potential risk factors like genetics, screen time, and educational stress,³¹ implementing large-scale interventions remains challenging. After extensive research, outdoor activities have emerged as one of the simplest and most cost-effective methods for myopia prevention.^{8,9} Engaging in outdoor activities for at least 2 hours per day or 14 hours per week has effectively prevented and controlled myopia development.³² Outdoor environments offer high light levels and diverse visual stimuli, increasing high-frequency visual signals to the eyes.³³ Exposure to ultraviolet or violet light from sunlight may boost retinal dopamine secretion, slowing down axial length growth. Studies assessing sunlight exposure through conjunctival ultraviolet autofluorescence (UVAF) have found a negative correlation between UVAF levels and myopia.³⁴ Animal models have demonstrated that brighter outdoor light during the day prompts greater dopamine release in the retina, which inhibits axial length growth. This protective effect may involve the D2 dopamine receptor in species such as chicks and tree shrews.^{18,19} In epidemiological research, wearable devices have facilitated data collection on individual behavior. For instance, Read³⁵ utilized Actiwatch to measure average daily light intensity, revealing that light levels exceeding 3000 lux were protective against myopia. Similarly, Wu,⁹ employing another wearable device called HOB0, found that light exposure exceeding 1000 lux reduced the risk of myopia progression by 35%.

In a large-scale epidemiological survey conducted by Guo,³⁶ a 10° increase in longitude was linked to a notable 0.39-fold decrease in myopia risk. Conversely, a 10° increase in latitude was associated with a substantial 27.10-fold increase in the risk of myopia. Additionally, Hua³⁷ discovered a correlation between higher latitudes and increased myopia rates, particularly in regions with reduced sunlight. Similarly, Tang observed a higher prevalence of myopia in northern China compared to the southern regions.³⁸ Given that the protective effect of outdoor activities against myopia is probably attributed to light exposure intensity, Donovan conducted a study in Guangzhou, China.³⁹ They found that children experienced faster myopia progression during winter compared to summer. The above evidence indicates a potential association between changes in natural sunlight conditions and the onset and progression of myopia in the region.

It is possible that natural factors tend to have less direct influence on individual health. May the amount of outdoor time influence the course of an individual's myopia more effectively. However, the external environment is often the basis for influencing group behavior,⁴⁰ similar to the development of urbanization, which is also a macro condition that comprehensively affects the prevalence of group myopia.¹² Future research endeavors could investigate whether children who spend more time outdoors under similar sunshine conditions exhibit lower myopia prevalences. Moreover, it is worth noting that non-cycloplegic autorefraction may have contributed to overestimating myopia prevalences, particularly among younger children, such as those in the kindergarten group in this study. Nonetheless, rapid myopia screening has facilitated large-scale epidemiological studies, making ophthalmic examinations more accessible to a broader population segment.

Our study is not without drawbacks. We did not perform biology measurements, such as ocular axis length due to equipment limitation. Besides, we would also like to indicate that the association between sunshine and myopia should be analyzed under similar condition of residential or sociocultural background. The influences on myopia are heterogeneous, so the influence of sunshine on myopia is unlikely to be fully consistent across countries or regions. In fact, the data of sunlight could not accurately represent the long-term exposure of children because of design of cross-sectional analysis.

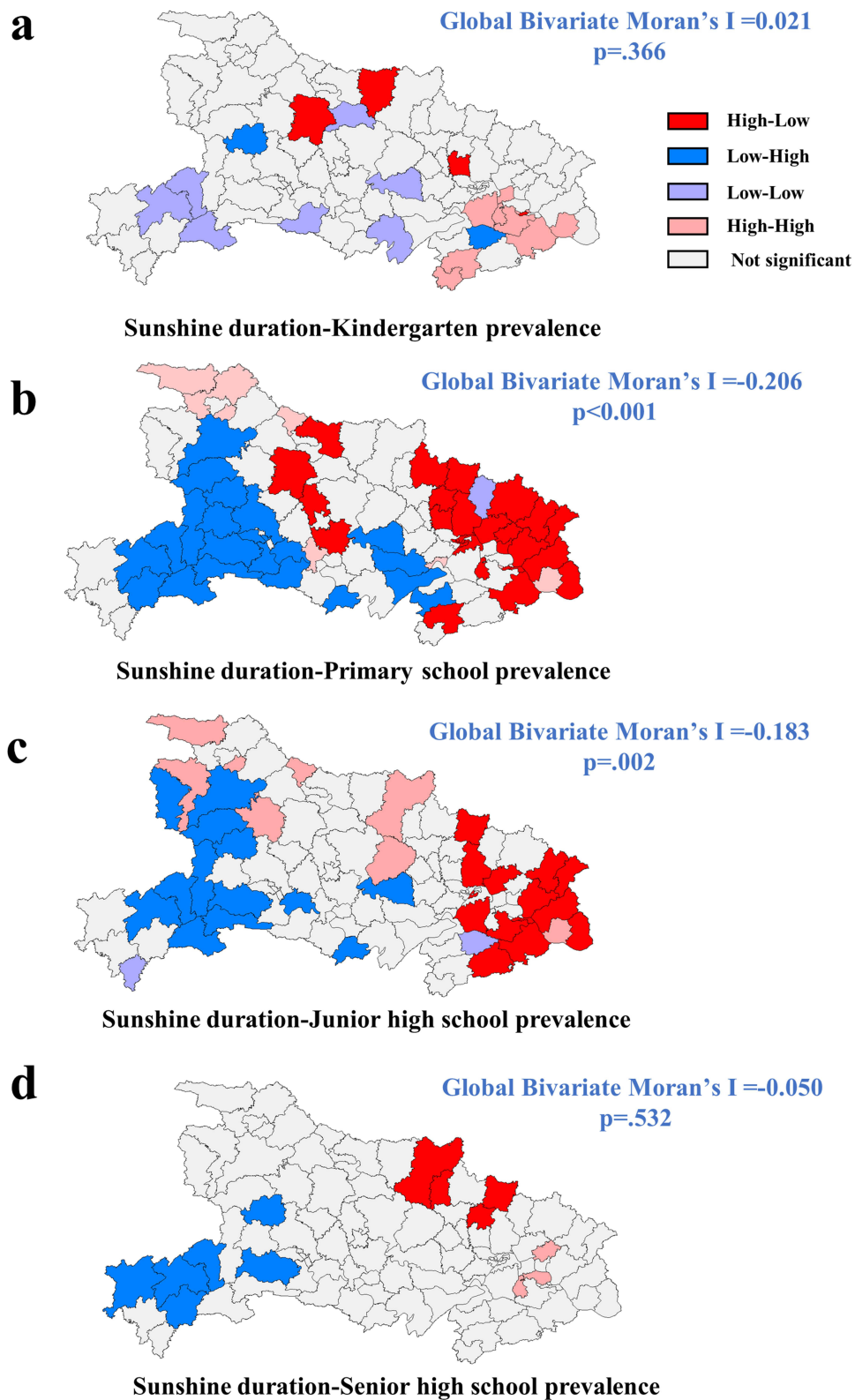


Figure 6 Local spatial analysis of sunshine hours and myopia rate of young children in Hubei Province LISA. (a) kindergarten; (b) primary school; (c) junior high school; (d) senior high school; The blue part represents the clustered areas with low sunshine and high myopia rates, and the red part represents the clustered areas with high sunshine and lower myopia rates.

Therefore, a combination of assessing the intensity of children's outdoor activities would more accurately reflect the conclusion.

In short, the evidence and findings suggest that sunlight conditions will likely influence the prevalence and distribution of myopia in Hubei. This influence may become more apparent when observed across a broader population or geographic range. The study offers potential implications for promoting active outdoor activities and increased sunlight exposure among children.

Conclusion

The study revealed differences in myopia prevalences and mean spherical equivalent refraction (SER) across varying sunshine conditions. Regions characterized by poorer sunshine exhibited higher myopia prevalences and lower mean SER. Additionally, a negative correlation was observed between myopia prevalence and sunshine duration at the populational and spatial levels. This association was particularly pronounced among primary students (grade 1–6), whose age are approximately 6–12 years old. Enhancing refractive development monitoring or encouraging outdoor activities may represent a potential strategy for myopia prevention, particularly in regions with inadequate sunshine conditions. Schools and society need to support sunshine exposure possibilities for school-aged children, such as the outdoor activity theory (about 2 hours/day) in previous studies.^{15,41–45} This may achieve myopia prevention and control from a broader and economic public health perspective.

Data Sharing Statement

The data are available in the Myopia Prevention and Treatment Centre for Children and Adolescents of Hubei Province. However, restrictions apply to the availability of these data. Myopia rates for each region cannot be directly presented for data management requirements. To protect the patient's privacy, ask the corresponding author and show justification if necessary.

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Ethics Approval and Informed Consent

This study was conducted by the Declaration of Helsinki and approved by the Ethics Committee of Renmin Hospital of Wuhan University (WDRY2020-K211 and WDRY2022-K010). Informed consent was obtained from all subjects or their legal guardians. Through parent meetings held at the beginning of the term, all students' guardians were approached by teachers for agreement. Parents who did not wish to take the examination could verbally inform the teachers. Other subjects will be viewed to have given verbal informed consent. Verbal informed consent process was acceptable and approved by the Ethics Committee of Renmin Hospital of Wuhan University.

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Disclosure

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