• Investigation •

Prevalence and risk factors of myopia among school-aged children and adolescents in Xi'an, China

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Abstract

● **AIM:** To evaluate the prevalence of myopia and identify its associated risk factors among children and adolescents in Xi'an, China.

● **METHODS:** In a school-based cross-sectional design, students ranging from kindergarten to high school across Xi'an were enrolled. Ophthalmic examinations were performed to assess refractive status *via* non-cycloplegic refraction. Myopia was defined as SE≤-0.5 D, with stratification into mild (SE: ≤-0.5 to >-3.0 D), moderate (SE: ≤-3.0 to >-6.0 D), and high myopia (SE≤-6.0 D). Data on potential risk factors such as age, gender, and educational level were obtained through structured questionnaires.

● **RESULTS:** The study included 156 416 participants, with 81 389 boys (52.0%) and 75 027 girls (48.0%). The prevalence rates of myopia were 65.67% for boys and 68.83% for girls. Data collection occurred over two consecutive years, 2021 and 2022, with 78 849 and 77 567 participants, respectively. The prevalence of myopia was 67.65% in 2021 and decreased slightly to 66.71% in 2022. The high myopia rates were 3.85% and 3.43% for these years, respectively. Analysis revealed significant risk factors including gender, age, and educational level, with a distinct positive correlation between increased educational level and higher myopia prevalence. Notably, both genders exhibited a significant decrease in moderate myopia over the study period, with reductions of 1.7% and 1.2%.

● **CONCLUSION:** This comprehensive study underscores the substantial prevalence of myopia among school-aged children and adolescents in Xi'an, marking it as a significant public health concern. The correlation with higher educational levels suggests the need for targeted interventions aimed at myopia prevention and management. These findings contribute critically to the body of knowledge necessary for formulating effective public health strategies in Xi'an and potentially other similar regions.

● **KEYWORDS:** myopia; high myopia; prevalence; risk factors; educational level

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INTRODUCTION

Myopia, characterized by the abnormal elongation of the eyeball coupled with an increase in refractive power, has emerged as a pressing clinical and public health concern worldwide[1-2]. Recent decades have witnessed a sharp escalation in the prevalence of myopia, drawing global attention. Projections indicate that by 2050, half of the world's population will be affected by myopia, with cases of high myopia expected to surge to 938 million[3]. This trend is especially pronounced in East Asian countries such as China, South Korea, and Singapore, where prevalence rates among adolescents reach 69% by age 15, escalating to 90% in early adulthood, with high myopia rates nearing 20%[4-7]. The progression of myopia is typically irreversible and tends to intensify in severity, potentially leading to serious ocular complications, including retinal detachment, myopic maculopathy, and choroidal neovascularization[8-9]. These complications are detrimental not only to individual health

but also impose significant burdens on societal and economic resources[10].

In China, the myopia scenario is particularly acute among children and adolescents, where it ranks among the highest globally[7]. Marked regional disparities are evident, as demonstrated by a study in Yiwu, Zhejiang Province, which reported a myopia prevalence of 63% and a high myopia rate of 9.4% among students aged 5 to 20y[11]. Conversely, a study in Haikou, Hainan Province in southmost China reported myopia rates of 46% with high myopia at 1%[12], and Qinghai, located in the northwestern region, showed a myopia prevalence of 29.8% and high myopia at 0.9%[13]. Despite these variations, the general trend across China points to an ongoing rise in myopia rates, underscored by data from Beijing showing an increase in prevalence from 64.9% to 70.9% from 2014 to 2016, with high myopia rates escalating concurrently[14-15]. Therefore, conducting epidemiological studies on high myopia among children and adolescents in specific regions is crucial for developing effective and appropriate public health strategies and measures for myopia prevention and control.

Given these circumstances, Xi'an—the largest city in northwestern China, housing approximately one-third of the province's population—provides a unique demographic and environmental context for the examination of myopia[16]. Capitalizing on this backdrop, we initiated a comprehensive myopia screening initiative over the years 2021 and 2022. This study was designed to assess the prevalence of myopia among the youth in Xi'an and to identify potential risk factors contributing to its emergence and escalation.

PARTICIPANTS AND METHODS

Ethical Approval This comprehensive cross-sectional study received approvals from the Ethics Committees of Shaanxi Eye Hospital, Xi'an People's Hospital (Xi'an Fourth Hospital), and the Affiliated People's Hospital of Northwest University (Ethical approval number: 20210086), adhering strictly to the Declaration of Helsinki principles. Written informed consent was obtained from the legal guardians of all participants before the commencement of the study.

Study Design and Population The researchers thoroughly explained the study's objectives and methodologies to potential participants during the recruitment phase. Conducted over the years 2021 and 2022, the study aimed to evaluate the prevalence of myopia and its associated risk factors among children and adolescents in Xi'an, located in northwest China. A total of 156 416 children and adolescents from Xi'an participated in this study, with an age range from 4.3 to 19.8y.

To standardize the classification of educational levels, participants were categorized into kindergarten, primary school, junior high school, and senior high school, in accordance with the educational structure in Xi'an. Specifically, kindergarten includes ages 4.3 to 8.2y, primary school spans ages 7.6 to 13.7y, junior high school covers ages 12.8 to 15.3y, and senior high school includes ages 14 to 19.8y.

Ophthalmic Examination and Questionnaire Refractive status was assessed using a desktop automatic computerized refractometer, compliant with the ISO 10342 standard for Ophthalmic Instruments-Refractors. To ensure accuracy, the instrument was calibrated daily using a standard simulated eye, with the cylindrical lens adjustment set to a negative value. Three measurements were taken for each eye, and if any two readings of spherical equivalent (SE) differed by more than 0.50 diopters (D), additional measurements were performed to compute an accurate average. A structured questionnaire was employed to collect data on potential risk factors including age, gender, grade, and ethnicity.

Definition of Refractive Status Spherical equivalent refraction (SER) was calculated by adding the spherical diopter to half of the cylindrical diopter value (SER=sphere+1/2 cylinder). Myopia was defined as an SE of -0.50 D or less and was further categorized into three levels: low (SE: ≤-0.5 to >-3.0 D), moderate (SE: ≤-3.0 to >-6.0 D), and high myopia (SE: ≤-6.0 D). Non-myopia was defined for SEs ranging from -0.50 to +1.00 D, without any history of eyewear use or ocular diseases. Hyperopia was determined as an SE of +1.00 D or more in individuals aged seven years and older, or +2.00 D in children younger than seven years. Cylindrical refraction was classified as positive corrective, and astigmatism was defined as a cylindrical refraction of at least 1.00 D (or 1.75 D for children under seven). Cases of single-eye refractive errors were categorized according to the specific condition present.

Statistical Analysis Continuous variables were presented as means±standard deviation (SD), and categorical variables as frequencies. The prevalence of myopia was expressed as a percentage with 95% confidence interval (CI). Independent samples *t*-tests were utilized to investigate differences between groups, while R×C Chi-square tests analyzed the distribution differences among groups. Spearman's correlation was used to examine the relationship between SE and demographic factors such as age and grade. Stratified analyses assessed the prevalence differences across myopia categories. Univariate and multivariate logistic regression analyses were conducted to identify risk factors for various categories of myopia, designated as "low myopia/non-low myopia", "moderate myopia/non-moderate myopia", and "high myopia/non-high myopia" as dependent variables. Odds ratios (ORs) and 95%CIs were reported. Age was centered by subtracting the mean age from each participant's age to minimize multicollinearity with education level in subsequent analyses. All *P*-values were two-sided, with $P<0.05$ considered statistically significant.

RESULTS

Demographic Characteristics A total of 156 416 children and adolescents from Xi'an participated in this study, including 81 389 boys (52.0%) and 75 027 girls (48.0%), with an age range from 4.3 to 19.8y. Among the boys, 53 449 (65.67%) were myopic, while 51 638 (68.83%) of the girls were myopic. The average age of the boys was 13.3±3.28y, and that of the girls was 13.2±3.27y. Participants were categorized based on their educational level: kindergarten (3.40%), primary school (69.8%), middle school (16.5%), and high school (10.4%). The primary school stage had the highest number of participants (109 125), whereas the high school stage had the highest myopia rate at 93.53%. The study included data from Xi'an primary and secondary school students over 2y, 2021 and 2022, with 78 849 and 77 567 participants respectively. The overall myopia rate decreased by 0.94% from 2021 to 2022. The demographic characteristics of the participants are demonstrated in Table 1.

Table 1 Demographic factors associated with myopia in children and adolescents in Xi'an

Demographic factors	Myopia (*n*=105087)	Non-myopia (*n*=51329)	*P*	χ^2
Sex			<0.001	176.0995
Male	53449	27940		
Female	51638	23389		
Ethnic groups			<0.001	13.9085
Han	101587	49802		
Others	3500	1527		
Age, y			0.000	25225.51
3-6	40	174		
6-12	30193	35820		
12-18	59016	14188		
>18	15838	1147		
Education level			0.000	18886.51
Kindergarten	969	4356		
Primary school	65948	43177		
Junior high school	23026	2749		
Senior high school	15144	1047		
Year			0.000	15.48365
2021	53340	25509		
2022	51747	25820		

Refractive Status Assessment by Educational Stage in Xi'an We summarized the prevalence of myopia, hyperopia, and astigmatism among children and adolescents in Xi'an at different educational stages. At the kindergarten stage, most children had completed the emmetropization process, with only 2.54% (95%CI: 2.30%-2.80%) being hyperopic, and 87.65% (95%CI: 87.12%-88.16%) were non-myopic. However, as age and educational level increased, the proportion of hyperopic individuals decreased, reaching 1.56% (95%CI: 1.37%-1.76%) in high school. The proportion of myopia increased with age, with mild myopia peaking in middle school at 45.99% (95%CI: 45.38%-46.61%), and moderate and high myopia peaking in high school at 35.17% (95%CI: 34.43%-35.91%) and 8.50% (95%CI: 8.08%-8.94%) respectively. The fastest increase in mild myopia was observed from kindergarten to primary school (28.09%), while moderate and high myopia increased most rapidly from primary to middle school, growing approximately 3.56 times (6.88% to 24.52%) and 7.94 times (0.54% to 4.29%) respectively (Figure 1A). Interestingly, the prevalence of astigmatism also increased with educational level, reaching 54.98% (95%CI: 54.21%-55.75%) in high school, consistent with previous studies[17-19]. Detailed data are shown in Table 2. Besides, Figure 1B shows a significant decrease in SE with age in both boys and girls, indicating a marked progression in myopia severity. Notably, starting from the age of 12, a statistically significant difference in SE was observed between sexes, with females exhibiting higher SE values than males.

Changes in Myopia and High Myopia from 2021 to 2022 in Xi'an We recorded changes in the prevalence and number of myopia cases in Xi'an from 2021 to 2022 (Table 3). The overall myopia rate decreased from 67.81% in 2021 to 66.72% in 2022, with boys and girls showing similar trends, decreasing by 1.20% and 0.90% respectively. Additionally, the prevalence of various degrees of myopia also declined, with the largest decreases observed in moderate myopia for both boys (1.7%) and girls (1.2%). As shown in Figure 2A, the SE values of boys (-2.26±1.77 *vs* -2.14±1.73 D) and girls (-2.32±1.8 *vs* -2.23±1.77 D) decreased significantly from 2021 to 2022 (P<0.001), mostly within the mild and moderate myopia ranges. We also evaluated changes in SE values for mild, moderate, and high myopia from 2021 to 2022 (Figure 2B), with all three categories showing significant decreases (mild myopia: -1.28±0.71 *vs* -1.25±0.72 D; moderate myopia: -3.76±0.94 *vs* -3.71±0.95 D; high myopia: -6.88±1.5 *vs* -6.86±1.52 D), with significant changes observed in mild and moderate myopia (P<0.001).

Exploration of Myopia-Related Risk Factors In this study, we explored factors related to the development of myopia among primary and secondary school students in Xi'an. We found a significant negative correlation between SE in both eyes and age and educational level (P<0.001). We conducted logistic regression analysis to investigate the associations between gender, age, and educational level with different degrees of myopia (Table 4). Univariate regression analysis showed that girls had a higher risk of myopia compared to boys across all myopia degrees: mild myopia (OR: 1.13, 95%CI: 1.10-1.15, P<0.001), moderate myopia (OR: 1.20, 95%CI: 1.16-1.23, P<0.001), and high myopia (OR: 1.28, 95%CI: 1.21-1.35, P<0.001). The risk increased with age. Multivariate analysis yielded consistent results, showing an increased myopia risk in girls after adjusting for other variables. Higher myopia prevalence was associated with older age and higher

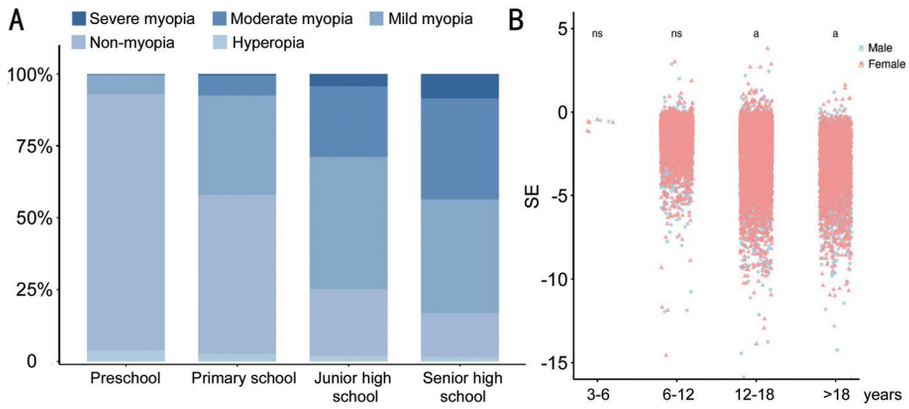

Figure 1 Refractive status across educational levels in Xi'an A: Proportion of refractive status (non-myopia, hyperopia, mild myopia, moderate myopia, and severe myopia) in different educational stages; B: Spherical equivalent (SE) values across different age groups and genders. Significance levels: [a]*P*<0.001; ns: Not significant.

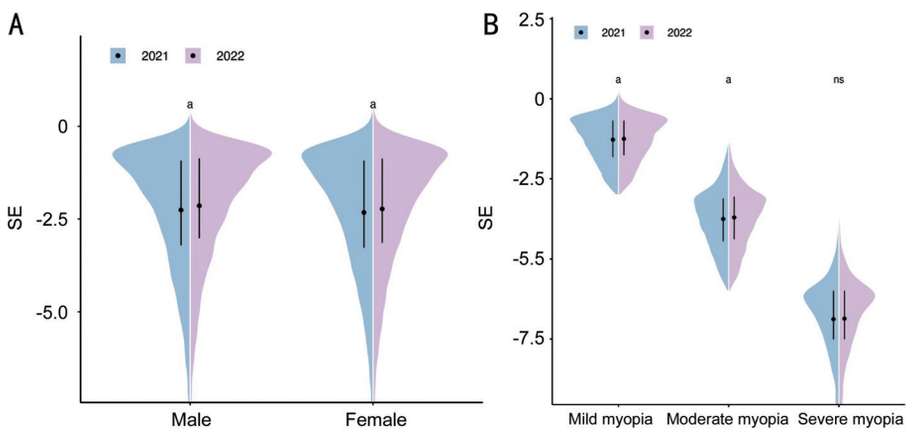

Figure 2 Temporal changes in myopia and high myopia prevalence in Xi'an: 2021-2022 A: SE values for males and females in 2021 and 2022; B: SE values for mild, moderate, and severe myopia in 2021 and 2022. SE: Spherical equivalent. Significance levels: [a]*P*<0.001; ns: Not significant.

Table 2 The proportion of refractive status at different educational stages in Xi'an (95%CI), %

Education level	Non-myopia	Mild myopia	Moderate myopia	High myopia	Hyperopia	Astigmatism
Kindergarten	87.65 (87.12-88.16)	8.90 (8.46-9.37)	0.75 (0.63-0.91)	0.16 (0.10-0.24)	2.54 (2.30-2.80)	15.55 (14.99-16.14)
Primary school	55.27 (54.98-55.57)	34.68 (34.40-34.96)	6.88 (6.73-7.03)	0.54 (0.50-0.59)	2.63 (2.53-2.72)	31.49 (31.22-31.77)
Middle school	23.38 (22.86-23.90)	45.99 (45.38-46.61)	24.52 (24.00-25.05)	4.29 (4.05-4.55)	1.81 (1.65-1.98)	50.12 (49.51-50.73)
High school	15.32 (14.77-15.88)	39.46 (38.71-40.22)	35.17 (34.43-35.91)	8.50 (8.08-8.94)	1.56 (1.37-1.76)	54.98 (54.21-55.75)

educational levels. However, in multivariate analyses of moderate and high myopia, age was not a significant factor and even appeared as a protective factor (OR: 0.97, 95%CI: 0.95-1.00, *P*=0.073; OR: 0.84, 95%CI: 0.87-0.97, *P*=0.004), possibly due to increased interventions with age. Educational level consistently appeared as a significant risk factor in both univariate and multivariate analyses, with higher OR values in multivariate analyses, particularly for high myopia, where the OR reached 2.24, indicating a strong impact of educational level on high myopia.

DISCUSSION

In this study, we conducted a large-scale screening of myopia among children and adolescents in Xi'an, Shaanxi Province, China, for the years 2021 and 2022. The results showed that the overall prevalence of myopia among primary and secondary school students in Xi'an was 67.65% in 2021 and 66.71% in 2022, with high myopia rates of 3.85% and 3.43%, respectively. Despite a slight decrease, these rates are still significantly higher compared to the nationwide data from China for the period 1998 to 2016, which reported a myopia rate of 37.7% and a high myopia rate of 3.1% according to Dong *et al*[6]. Additionally, compared to other regions in China, such as Wenzhou[20], Urumqi[21], Weifang[22], and Hong Kong[23], Xi'an's myopia and high myopia rates remain among the highest[24]. Moreover, compared to the overall levels in Shaanxi Province, the myopia development trend in Xi'an is particularly severe. A recent cross-sectional study conducted in Shaanxi Province in 2021, which included participants from 107 schools across six cities, reported a myopia prevalence of 70.7% among school-aged children and adolescents[25].

Table 3 Myopia status by gender in Xi'an (2021-2022) *n* (%)

Myopia status	Male				Female			
	2021 (*n*=41240)	2022 (*n*=40149)	*P*	χ^2	2021 (*n*=37609)	2022 (*n*=37418)	*P*	χ^2
Visual status			<0.001	70.985			<0.001	24.969
Non-myopia	13960 (33.9)	13980 (34.8)			11549 (30.7)	11840 (31.6)		
Mild myopia	18230 (44.2)	18248 (45.5)			17155 (45.6)	17273 (46.2)		
Moderate myopia	7553 (18.3)	6660 (16.6)			7364 (19.6)	6902 (18.4)		
High myopia	1497 (3.63)	1261 (3.14)			1541 (4.10)	1403 (3.75)		

Table 4 Risk factors for different degrees of myopia in Xi'an mean±SD

Dependent: visual status	Myopia	Univariable analysis			Multivariable analysis		
		OR	95%CI	*P*	OR	95%CI	*P*
Mild (SE: <-0.5 to >-3.0 D)							
Sex		1.13	1.10-1.15	<0.001	1.19	1.16-1.22	<0.001
Male	36478 (51.4%)						
Female	34428 (48.6%)						
Age	13.3±2.9	1.34	1.34-1.35	<0.001	1.05	1.03-1.07	<0.001
Grade	5.8±2.8	1.38	1.37-1.38	<0.001	1.32	1.29-1.34	<0.001
Moderate (SE: <-3.0 to >-6.0 D)							
Sex		1.20	1.16-1.23	<0.001	1.38	1.32-1.43	<0.001
Male	14213 (49.9%)						
Female	14266 (50.1%)						
Age	15.8±3.0	1.70	1.69-1.71	<0.001	0.97	0.95-1.00	0.073
Grade	8.1±2.8	1.77	1.76-1.79	<0.001	1.83	1.77-1.88	<0.001
High (SE: <-6.0 D)							
Sex		1.28	1.21-1.35	<0.001	1.61	1.53-1.77	<0.001
Male	2758 (48.4%)						
Female	2944 (51.6%)						
Age	17.0±2.8	1.79	1.77-1.81	<0.001	0.84	0.87-0.97	0.004
Grade	9.3±2.6	1.87	1.85-1.89	<0.001	2.24	1.93-2.17	<0.001

OR: Odds ratio; CI: Confidence interval; SE: Spherical equivalent; D: Diopters. Logistic regression models with mild myopia (SE: -0.5 to -3.0 D), moderate myopia (SE: -3.0 to -6.0 D), and high myopia (SE: ≤-6.0 D) as dependent variables, using the corresponding non-myopia groups as references.

Compared to previous epidemiological studies of myopia in Xi'an, such as Zhao *et al*'s[16] study in 20 key schools (with a myopia rate of 75.7% and high myopia rate of 9.7%) and Ye *et al*'s[26] survey among primary school students in Xi'an (with a myopia rate of 57.1% and high myopia rate of 1.0% among the 6-13y age group), our study shows a persistent high prevalence. Compared to our study, the number of subjects and scope included are more comprehensive and extensive, making it more suitable for filling an important gap in the myopia prevalence data in China.

We detailed the distribution of refractive statuses across different educational stages (Table 2, Figure 1A), finding that the primary school stage is the primary period for the onset of myopia, whereas myopia progresses most rapidly during the middle school stage. Thus, myopia prevention should start in primary school and intensify in controlling myopia severity as educational levels advance. Such findings can provide targeted guidance for myopia prevention and intervention at various stages. Additionally, we analyzed the changes in myopia prevalence rates and spherical equivalents among different genders of primary and secondary school students in Xi'an for 2021 and 2022 (Table 3 and Figure 2). The results show a declining trend in the prevalence of moderate and high myopia, indicating the effectiveness of recent myopia intervention measures in Xi'an.

In our study, the prevalence of myopia was consistently higher among females than males in both years (2021: 69.29% *vs* 66.15%; 2022: 68.36% *vs* 65.18%). Risk factor regression analysis showed that being female was associated with a higher risk of myopia at all levels (Table 4), consistent with previous studies[27-28]. This may be related to the behavioral preference of Chinese girls for indoor activities, as well as hormonal levels[29-30] and genetic factors, such as the high myopia-associated rs9307551 gene[31]. Additionally, mutations in the cone protein-coding genes on the X chromosome are also linked to the onset of myopia, where the proportion

of L cones and L protein gene polymorphism is higher in females due to carrying two X chromosomes, thus posing a higher risk of myopia compared to males[32]. While the difference in prevalence is statistically significant, its practical implications for public health interventions in myopia control may be limited. However, this finding highlights the need for further research into gender-specific risk factors for myopia development. Although age can act as an independent risk factor for the onset of myopia, it is interesting to note that in multivariate regression analysis, the impact of older age becomes non-significant or even protective in cases of moderate and high myopia (OR: 0.97, *P*=0.073; OR: 0.92, *P*=0.004). This could be related to older individuals being more conscious of taking myopia intervention measures[33-34]. In populations with more severe myopia, parents are more likely to pursue active treatment strategies rather than adopting a conservative approach towards mild myopia. Finally, academic progression, accompanied by increased academic pressure, more study time, and less outdoor activity, significantly accelerates myopia development. Therefore, the elevation in educational levels is a crucial risk factor for the progression of myopia[35-36].

This study's strength lies in its utilization of a large-scale, population-based sampling method, making it one of the largest myopia screening studies conducted in Xi'an to date; it achieved a relatively comprehensive sample from Xi'an with a high response rate. However, there are several limitations to note. First, the distribution of sample sizes across educational stages was uneven, with over 100 000 samples from primary school stages and comparatively fewer from other stages. Additionally, as a cross-sectional study conducted in 2021 and 2022, it cannot establish causal relationships. A key limitation is that the study does not track individual changes over time, which limits the ability to establish a causal relationship between educational level and myopia. Another limitation is the use of non-cycloplegic refraction, which was adopted due to the large-scale nature of the survey. Although this approach may have resulted in an overestimation of myopia prevalence, the consistency of the observed patterns across different subgroups and the limited effect on the prevalence of high myopia suggests that the main conclusions of the study remain robust and credible. Finally, the study mainly assessed the correlation between myopia prevalence and some basic potential risk factors such as age, gender, and educational level, lacking comprehensive questionnaire data on children's daily visual habits, learning habits, lifestyle, and parents' myopia and visual conditions. Therefore, future studies are anticipated to collect more comprehensive data on factors related to myopia.

In conclusion, this study represents the largest epidemiological investigation of childhood and adolescent myopia in Xi'an, Northwestern China. The results indicate that the rates of myopia and high myopia among primary and secondary school students in Xi'an are higher than the national average and rank among the highest. Analysis of risk factors for myopia revealed that the prevalence of myopia is significantly associated with an increase in educational level (grade). Our findings underscore the myopia situation in Xi'an, highlighting the importance of prevention and control measures for myopia in Northwestern China, and call for increased attention and effective intervention strategies.

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Authors' Contributions: Guo YM participated in the data collection, analysis, and processing, and wrote the initial manuscript. Liu GC contributed to graphic visualization and optimization. Wei JH and Wang JQ were involved in data collection, processing, and manuscript proofreading. Bi JJ and Huang J assisted with the writing, graphical visualization, and coordination of the entire process. Zhou DX was responsible for project design and strategic planning and acted as the Co-Corresponding Author. Ye L provided project funding and institutional support, supervised the overall study process including the final critical appraisal and revision of the manuscript, and acted as the First Corresponding Author.

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