scientific reports

OPEN

Rising burden of myopia among South Korean young adults based on 13-year trends, associated factors, and projections to 2050

Yeonsu Lee[1], Jongwook Lee[2], Daeun An[3], Kyoung Yul Seo[4], Sangchul Yoon[5]✉ & Nathan Congdon[6,7]

To investigate long-term and projected trends of myopia and high myopia among young South Korean males and to evaluate associated sociodemographic risk factors. A repeated cross-sectional analysis was conducted using medical records from 4,063,091 19-year-old conscripts between 2011 and 2023. Logistic regression identified myopia risk factors, while linear regression assessed temporal trends. Projection modeling estimated future prevalence through 2050. Myopia prevalence increased from 50.6% in 2011 to 59.8% in 2023, and high myopia from 14.3% to 17.7%. Higher education was strongly associated with both conditions ($P<0.001$), yet the gap narrowed. In 2011, odds of myopia and high myopia were over threefold higher in the most educated versus least educated groups (OR = 3.20 and OR = 3.03), but by 2023 had declined to approximately twofold (OR = 2.00 and OR = 1.99). Urban residents consistently showed higher risk compared with rural dwellers ($P<0.001$), though disparities also narrowed (high myopia OR = 1.52 in 2011 vs. OR = 1.37 in 2023). Body stature indicators showed no consistent associations. Projection models suggested prevalence may reach 84% for myopia and 28% for high myopia by 2050. In this nationwide study, myopia and high myopia rose substantially over 13 years with narrowing sociodemographic disparities. Projections indicate further escalation, underscoring the urgent need for national prevention strategies.

Myopia poses a growing public health threat worldwide[1–4]. Prevalence rates have been steadily increasing across many regions over the past few decades[5,6]. A systematic review and meta-analysis predicted a striking rise in myopia, with nearly 5 billion people expected to be myopic and 1 billion with high myopia by 2050[6,7]. The rising burden of myopia is complicated by concurrent increases in high myopia, which elevates the risk of more serious potentially blinding complications such as glaucoma, cataract, and myopic macular degeneration[8].

Myopia risk is known to vary by ethnicity with persons of Asian descent having a particularly high burden compared with other ethnic groups. The highest prevalence among children and young adults is found in countries in East and Southeast Asia[6,9,10] including South Korea (96.5%), Taiwan (84%), Singapore (81.6%) and China (80% in Shandong in the North, and 84.1% in Guangzhou)[11–15]. A population-based study conducted in the United States has reported significantly higher myopia prevalence among Asian vs. non-Hispanic white children[16]. Environmental factors such as less time spent outdoors and early, high levels of near work due to academic pressure have been associated with the myopia epidemic in East and Southeast Asia[7,17]. Regarding urbanization, several studies have consistently reported a higher myopia prevalence among urban vs. rural dwellers[18,19], including in Korea, between rural Jeju (83.8%) and urban Seoul (96.5%)[20].

The role of other potential risk factors for progression of myopia, including height and BMI, remains controversial. Change in height and BMI were positively correlated with increases in myopia among primary school children in Taiwan ($n = 344$, $P < 0.05$) and China ($n = 3090$, $P < 0.001$)[21,22], but this association is inconsistent across other studies[11,23,24].

[1]Faculty of Epidemiology and Population Health, London School of Hygiene & Tropical Medicine, London, UK. [2]Department of Agricultural Economics and Rural Development, Seoul National University, Seoul, Republic of Korea. [3]Health Economics and Market Access, Amaris Consulting, London, UK. [4]Department of Ophthalmology, Severance Hospital, Institute of Vision Research, Yonsei University College of Medicine, Seoul, Republic of Korea. [5]Department of Global Health, Graduate School of Public Health and Healthcare Management, The Catholic University of Korea, Seoul, Republic of Korea. [6]Centre for Public Health, Queen's University Belfast, Belfast, UK. [7]Orbis International, New York, US. ✉email: syoon22@catholic.ac.kr

To the best of our knowledge, previous studies of myopia in Korea have been limited by smaller sample sizes, shorter study periods or restrictions to specific regions such as Seoul, and no nationwide projections have been reported[11,25,26]. These limitations reduce the ability to capture long-term secular trends or to generalize findings on the national population. As a result, the broader implications of myopia trends in Korea, and their potential relevance for global public health, have not been fully explored.

In this study, we analyzed health examination data from more than four million 19-year-old male conscripts between 2011 and 2023 to provide the most up-to-date nationwide estimates of myopia and high myopia in South Korea. We further examined sociodemographic risk factors such as education and urbanization and applied regression modeling to project prevalence through 2050. As South Korea is among the most myopic countries worldwide, it offers a unique case study and a window into the future for other regions experiencing rapid increases in myopia. By leveraging an unprecedented dataset and focusing on globally relevant risk factors, our findings not only inform national health policy but also contribute valuable insights to the international understanding of the myopia epidemic.

Methods
Data source
This study employed a repeated cross-sectional analysis of electronic physical examination data collected by the Military Manpower Administration (MMA) between 2011 and 2023. All records were stored in a computerized government database and linked to the national public database. The study adhered to the principles outlined in the Declaration of Helsinki and was approved by the Institutional Review Board (IRB) of the Armed Forces Medical Command (AFMC-19081-IRB-19–057). Under the Military Service Act of the Republic of Korea, conscription physical examinations are mandated by law and are conducted without individual informed consent as part of a statutory administrative process[27]. Due to the retrospective nature of the study using de-identified government records, the requirement for informed consent was deemed unnecessary under national regulations and was waived by the IRB.

Geographic boundary data used for map visualization were obtained from publicly available district level (si/gun/gu) administrative boundary shapefiles downloaded from the Korean Open Government Data Portal (https://www.data.go.kr/data/15125045/fileData.do). All maps were created by the authors using R software version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria) with the sf and ggplot2 packages.

Study population
All 19-year-old males in South Korea who underwent the physical examination for conscription conducted by the MMA between 2011 and 2023 were included in this analysis (Supplementary Fig. 1). In South Korea, military service is mandatory for all male citizens, and a preliminary evaluation for military service eligibility is conducted at the age of 19. Depending on the physical examination results, enlistment occurs between ages of 19 and 37. The final study population included 4,063,091 Korean males (Table 1). The examination coverage, calculated as the proportion of 19-year-old males examined relative to the total population in that age group,

Variable	*N*	Proportion, %	Mean ± SD
Age, years			19.0 ± 0.5
Sex			
Male	4,063,091	100.0	
Educational level			
High school graduate or less	877,633	21.6	
Studying in 2-year college	731,356	18.0	
Studying in 3- to 4-year university	2,382,749	58.6	
Student master's degree or higher	73,353	1.8	
Urban index (%)			
Urban (81–100)	3,538,969	87.1	
Sub-urban (41–80)	422,562	10.4	
Rural (0–40)	101,560	2.5	
Height, cm			173.8 ± 6.2
Weight, kg			70.3 ± 15.0
BMI [c], kg/m^2			23.2 ± 4.6
Underweight (< 18.5)	455,066	11.2	
Normal (18.5–23)	1,800,941	44.3	
Overweight (> 23- <25)	670,409	16.5	
Obese (≥ 25)	1,136,675	27.9	
SBP [a], mm Hg			125.1 ± 13.1
DBP [b], mm Hg			73.7 ± 9.2

Table 1. Demographic and characteristics of Participants. [a] Systolic Blood Pressure. [b] Diastolic Blood Pressure. [c] Body Mass Index.

averaged 97.81% during the study period[28,29]. Individuals who underwent the examination more than two years beyond the standard age of 19 were excluded, given that such delays generally reflected exceptional circumstances such as medical conditions, overseas residence or extended academic studies.

Data collection

Physical examinations followed a standardized procedure using a computer-based system with results automatically entered into a centralized digital database to ensure completeness and reliability compared with the previous paper-based system. The medical profiling process consisted of three stages[30]. First, all candidates for conscription were obligated to complete a personal history questionnaire detailing name, date of birth, address, name of head of household, etc. The highest educational level was automatically matched from the national educational database using the candidate's social security number. Second, candidates were required to complete a questionnaire describing their medical history. Lastly, they underwent a physical examination conducted by trained medical officers, which included an assessment of psychological status, height and weight, urine and blood testing, chest radiography, blood pressure, color vision and visual acuity.

Visual acuity testing followed a standardized protocol. Uncorrected visual acuity was measured using a Snellen chart with internal illumination under ambient lighting conditions of 200 lx, adhering to international standards for visual acuity assessment (80–320 cd/m²). Each eye was tested separately with the fellow eye covered with an occluder. Participants able to correctly read all or all but one letter on the top line (6/6) of the chart in each eye without optical correction were classified as emmetropic. Those not meeting this criterion underwent automated refraction for each eye using an automatic refraction tester (RF-10, Canon Inc., Tokyo, Japan), administered by an ophthalmic medical officer.

Definitions

Body stature

Height and weight were measured using the digital scale and recorded in centimeters (cm) and kilograms (kg) to one decimal place. Subjects were instructed to stand upright with their eyes and ears aligned horizontally while wearing the examination gown to ensure accuracy. Body mass index (BMI) was calculated as weight (kg) divided by height in meters squared (m²). BMI was categorized as underweight (< 18.5), normal (18.5–22.9), overweight (23.0–24.9.0.9), and obese (≥ 25). The classification criteria were applied according to the recommendations of the World Health Organization (WHO) Regional Office for the Western Pacific and the WHO Expert Consultation on BMI cut-offs for Asian populations, which account for the higher risk of obesity-related conditions at lower BMI thresholds compared with international standards[31,32].

Myopia

Refractive error was measured with a non-cycloplegic autorefraction device when uncorrected visual acuity was 0.3 or worse[30]. Spherical equivalent (SE) was calculated as spherical power + (cylindrical power/2). Myopia was defined as SE < − 0.50 D, and high myopia was classified as SE ≤ − 6.00 D[2526].

Educational level

The highest educational level was classified into four categories according to the Korean education system: high school graduate or lower, 2-year college degree, 3- to 4-year university degree and master's degree or higher. This information was automatically retrieved from the national education database through linkage with each individual's social security number. Although the physical examination was conducted at age 19, the educational information was obtained from an annually updated database, ensuring that any higher degree attained later was reflected in the records. As a result, the recorded educational level represents the highest degree either completed or in progress at the time of data retrieval, thereby minimizing misclassification. For analytical consistency, years of education were assigned as follows: 12 years for high school graduate or lower, 14 years for 2-year college, 16 years for university degree and 18 years for master's degree or higher. In South Korea, elementary and middle school education is compulsory, and nearly all students proceed to high school except in rare cases such as incarceration.

Urban index

The level of urbanization was quantified at the district level (si/gun/gu), which represents the primary administrative subdivision in South Korea. Within each district, smaller administrative sub-units are officially classified as either urban or rural according to population size[33]. Areas with fewer than 20,000 inhabitants are designated as rural, and those with 20,000 or more inhabitants are classified as urban[34]. The urban index for each district was calculated as the proportion of the population residing in urban sub-units relative to the total district population. For analysis, the index was categorized into three levels: rural (0–40%), sub-urban (41–80%) and urban (81–100%).

Statistical analysis

Risk factor and trend analyses

All analyses were performed using R version 4.2.2. Logistic regression and linear regression models were applied to assess the association between myopia and explanatory variables such as educational level, urban index, height, weight and BMI. Logistic regression was conducted for the years 2011, 2017 and 2023 to evaluate temporal changes in associations. 2017 was selected as the midpoint of the 13-year study period to allow balanced comparison with the earliest and most recent years.

Two logistic regression models were used. Model 1 was unadjusted, and Model 2 was adjusted for potential confounders. Odds ratios (ORs) with 95% confidence intervals (CIs) were reported. Statistical significance was assessed using the Wald test for individual regression coefficients and the likelihood ratio test for model comparison. The Wald test evaluated whether each explanatory variable was independently associated with myopia or high myopia, and the likelihood ratio test compared unadjusted and adjusted models to determine whether the inclusion of additional covariates significantly improved overall model fit. Two-sided P values < 0.05 were considered statistically significant. Temporal trends in the prevalence from 2011 to 2023 were evaluated using linear regression.

Projection modeling
Future prevalence of myopia and high myopia was projected through 2050 using regression-based models fitted to annual prevalence data from 2011 to 2023. Two models were employed: a linear regression model assuming a constant annual rate of change, and a logarithmic regression model accounting for potential deceleration in the growth rate over time. The models were specified as follows:

Linear regression:

$$Prevalence_t = \beta_0 + \beta_1 \times Year_t$$

Logarithmic regression:

$$Prevalence_t = \beta_0 + \beta_1 \times \log(Year_t)$$

Projected prevalence with corresponding 95% CIs was estimated at 5-year intervals from 2025 to 2050. Model performance was assessed using adjusted R^2 values and visual inspection of observed versus fitted trends. Predicted values were presented alongside observed data to evaluate continuity and model fit.

Results

Prevalence and trends of myopia and high myopia

Between 2011 and 2023, the prevalence of myopia among young males in South Korea increased from 50.6% to 59.8% ($P < 0.001$) and high myopia (≤ −6.00 D) rose from 14.3% to 17.7% ($P < 0.001$) (Table 2). The median spherical equivalent (SE) decreased in absolute value from − 1.00 D to −2.75 D during the same period (Supplementary Fig. 2).

Projected myopia and high myopia prevalence through 2050

Future prevalence was forecast using both linear and logarithmic regression models fitted to annual prevalence data from 2011 to 2023. The fitted equations were as follows:

Linear models:

$$Prevalence_t = 0.8883 \times Year_t - 1736.71\ (for\, myopia).$$

$$Prevalence_t = 0.3682 \times Year_t - 726.14\ (for\, high\, myopia).$$

Logarithmic models:

$$Prevalence_t = 1791.56 \times \log(Year_t) - 13577.65\ \text{(for myopia)}$$

$$Prevalence_t = 742.73 \times \log(Year_t) - 5635.12\ (for\, high\, myopia).$$

Exam year, y	Study population, *n*	Myopia prevalence, % (95% CI)	High myopia prevalence, % (95% CI)
2011	360,499	50.6 (50.4, 50.7)	14.3 (14.2, 14.4)
2012	355,444	51.3 (51.1, 51.4)	15.3 (15.2, 15.4)
2013	359,233	51.3 (51.1, 51.4)	15.6 (15.5, 15.7)
2014	358,189	51.3 (51.1, 51.5)	15.3 (15.2, 15.5)
2015	352,217	52.5 (52.3, 52.6)	14.9 (14.8, 15.0)
2016	345,692	54.6 (54.4, 54.7)	16.0 (15.9, 16.1)
2017	329,992	53.8 (53.6, 53.9)	16.4 (16.3, 16.6)
2018	314,437	55.0 (54.8, 55.1)	16.6 (16.5, 16.7)
2019	323,538	56.7 (56.5, 56.9)	17.6 (17.4, 17.7)
2020	265,738	59.1 (58.9, 59.3)	18.1 (18.0, 18.3)
2021	234,672	59.5 (59.3, 59.7)	19.2 (19.1, 19.4)
2022	236,101	59.5 (59.3, 59.7)	18.9 (18.7, 19.0)
2023	227,339	59.8 (59.6, 60.0)	17.7 (17.5, 17.8)

Table 2. 13-Year trends in myopia and high myopia prevalence in South Korea from 2011 to 2023.

Exam year, y	Myopia prevalence, % (95% CI)		High myopia prevalence, % (95% CI)	
	Linear	Logarithmic	Linear	Logarithmic
2025	62.1 (60.8, 63.4)	62.1 (60.8, 63.4)	19.6 (18.6, 20.5)	19.6 (18.6, 20.5)
2030	66.5 (64.5, 68.5)	66.5 (64.5, 68.5)	21.4 (19.9, 22.9)	21.4 (19.9, 22.8)
2035	71.0 (68.3, 73.7)	70.9 (68.2, 73.6)	23.2 (21.3, 25.2)	23.2 (21.2, 25.2)
2040	75.4 (72.0, 78.9)	75.3 (71.9, 78.7)	25.1 (22.6, 27.6)	25.0 (22.5, 27.5)
2045	79.9 (75.7, 84.0)	79.7 (75.5, 83.8)	26.9 (23.9, 29.9)	26.9 (23.8, 29.9)
2050	84.3 (79.4, 89.2)	84.1 (79.2, 88.9)	28.8 (25.2, 32.3)	28.7 (25.1, 32.2)

Table 3. Projected prevalence of myopia and high myopia in 5-year intervals from 2025 to 2050.

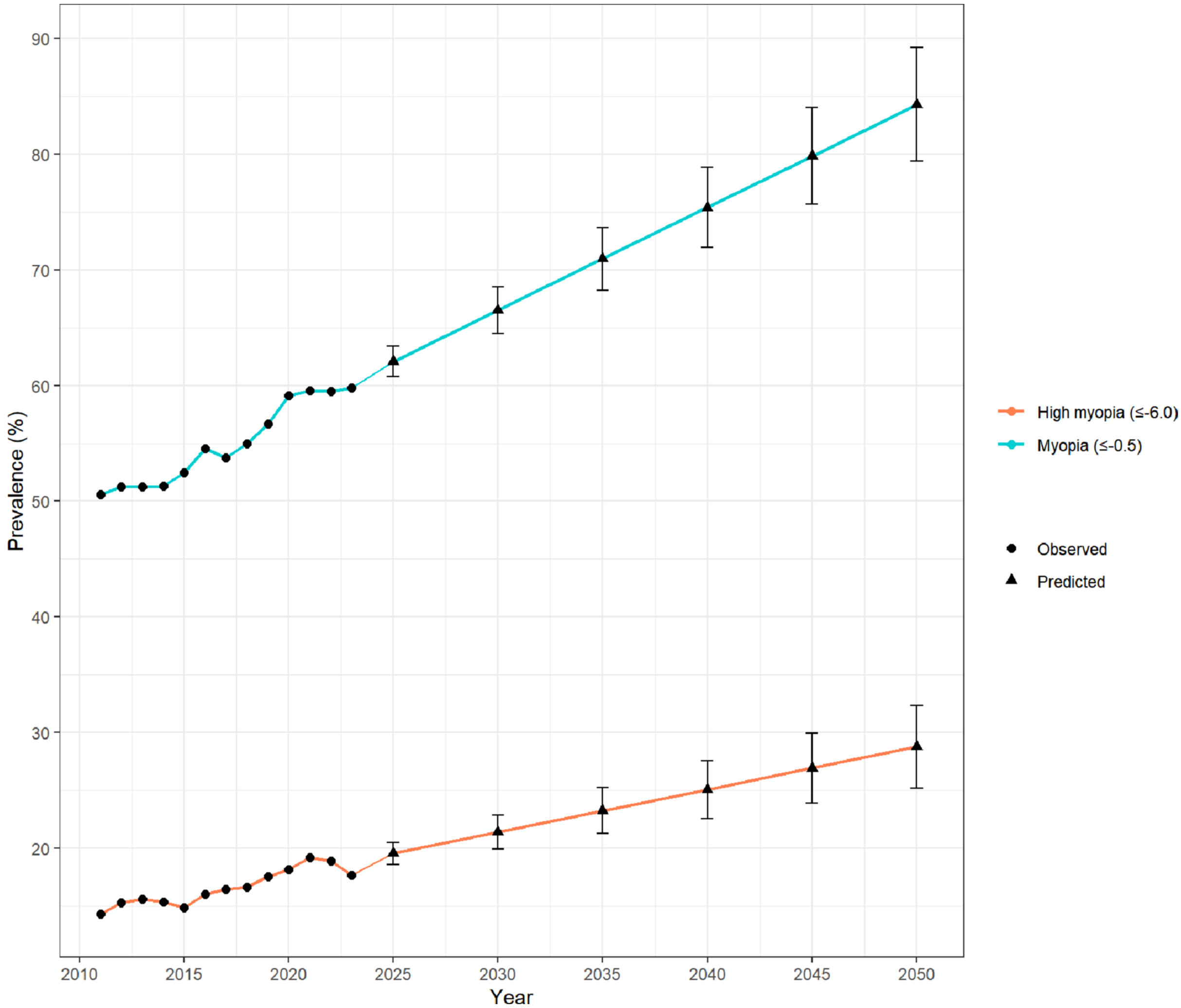

Fig. 1. Trends in observed and predicted prevalence of myopia and high myopia among 19-year-old males in South Korea from 2011 to 2050.

Based on these models, the prevalence of myopia in 19-year-old males is expected to rise from 62.1% (95% CI = 60.8–63.4%) in 2025 to 84.3% (95% CI = 79.4–89.2%) in 2050 under the linear model (Table 3). Similarly, the logarithmic model projected an estimate of 84.1% (95% CI = 79.2–88.9%) by 2050. The prevalence of high myopia is projected to increase from 19.6% (95% CI = 18.6–20.5%) in 2025 to 28.8% (95% CI = 25.2–32.3%) in 2050 using the linear model. Logarithmic estimates for high myopia were slightly lower but remained within overlapping CIs across all years. Both models demonstrated a consistent upward trend with minimal divergence, suggesting that the current trajectory of myopia and high myopia can be reliably approximated using linear methods through 2050. Figure 1 presents the observed prevalence of myopia and high myopia from 2011 to 2023 with projections through 2050 based on linear regression models. The figure shows a clear upward trend for both conditions with fitted values closely aligned to observed data. Adjusted R^2 values were 0.935 for both the linear and log-linear models of myopia, and 0.824 for both models of high myopia.

Analysis of the risk factors for myopia and high myopia

Educational level

The highest educational level in the study population was as follows: 21.6% were high school graduates or less, 18.0% were enrolled in a 2-year college, 58.6% were studying at a 3- or 4-year university, and 1.8% held a master's degree or higher qualification (Table 1). Higher educational level was significantly associated with greater prevalence of both myopia and high myopia ($P < 0.001$) (Table 4). In 2011, a consistent increase was observed in the prevalence of myopia and high myopia as the level of education increased: High school graduates or lower had the lowest prevalence of myopia (36.99%) and high myopia (8.33%), while participants with a master's degree had the highest, 65.27%, and 21.61% respectively (both $P < 0.001$).

However, there was a potential shift in 2023: the difference between high school graduates or less and students attending a 2-year college was no longer statistically significant. The prevalence of myopia was 45.69% in high school graduates or less and 47.20% in 2-year college students with an adjusted odds ratio of 0.97 (95% CI = 0.94–1.00.94.00, $P = 0.081$), indicating no evident difference in risk. A similar pattern was observed for high myopia, where prevalence was 11.89% and 12.65% in the two groups, respectively, with no significant difference (OR = 1.01, 95% CI = 0.96–1.06, $P = 0.689$).

Overall, the educational disparity in myopia has gradually narrowed over the past decade. While in 2011 the odds of myopia and high myopia were more than threefold higher in the most educated group compared with the least educated (OR = 3.20 and OR = 3.03, respectively), by 2023 these odds ratios had decreased to approximately twofold (OR = 2.00 and OR = 1.99).

Urban index

87.1% of examinees were classified in the urban category (urban index 81–100) with the highest proportion residing in Seoul (Table 1). A significant correlation was observed between higher urban index and greater myopia prevalence (Table 5). The prevalence of myopia and high myopia was significantly higher in more heavily urbanized areas compared to rural areas ($P < 0.001$). While urbanization remained a significant risk factor for high myopia in 2023, the risk gap between urban and rural areas decreased compared to 2011. The risk of high myopia in urban areas compared to rural areas in 2011 (OR = 1.52, 95% CI = 1.41–1.64) decreased in 2023 (OR = 1.37, 95% CI = 1.27–1.48). A concentration of high myopia prevalence was observed in the Seoul

				Model 1 [a]	Model 2 [b]		
	Exam year, y	Education level	Prevalence, %	Odds ratio (95%CI)	Odds ratio (95%CI)	*P* Value [c]	*P* Value [d]
Myopia	2011	High school graduate or less	36.99	1.00	1.00	NA	< 0.001
		Studying in a 2-year college	41.41	1.20 (1.18,1.23)	1.22 (1.19,1.24)	< 0.001	
		Studying in a 3- to 4-year university	57.29	2.29 (2.24,2.33)	2.29 (2.25,2.34)	< 0.001	
		Master's degree student or higher	65.27	3.20 (3.08,3.33)	3.20 (3.08,3.33)	< 0.001	
	2017	High school graduate or less	45.80	1.00	1.00	NA	< 0.001
		Studying in a 2-year college	47.79	1.08 (1.06,1.11)	1.09 (1.07,1.11)	< 0.001	
		Studying in a 3- to 4-year university	58.76	1.69 (1.66,1.71)	1.69 (1.66,1.71)	< 0.001	
		Master's degree student or higher	71.40	2.95 (2.75,3.17)	2.92 (2.72,3.14)	< 0.001	
	2023	High school graduate or less	45.69	1.00	1.00	NA	< 0.001
		Studying in a 2-year college	47.20	0.97 (0.94,1.00)	0.97 (0.94,1.00)	0.081	
		Studying in a 3- to 4-year university	59.47	1.35 (1.32,1.39)	1.34 (1.31,1.38)	< 0.001	
		Master's degree student or higher	68.69	2.03 (1.90,2.18)	2.00 (1.87,2.14)	< 0.001	
High Myopia	2011	High school graduate or less	8.33	1.00	1.00	NA	< 0.001
		Studying in a 2-year college	9.89	1.21 (1.16,1.25)	1.22 (1.18,1.27)	< 0.001	
		Studying in a 3- to 4-year university	17.34	2.31 (2.24,2.38)	2.31 (2.24,2.38)	< 0.001	
		Master's degree student or higher	21.61	3.04 (2.89,3.19)	3.03 (2.88,3.18)	< 0.001	
	2017	High school graduate or less	12.24	1.00	1.00	NA	< 0.001
		Studying in a 2-year college	13.09	1.08 (1.05,1.11)	1.09 (1.05,1.12)	< 0.001	
		Studying in a 3- to 4-year university	19.10	1.69 (1.65,1.73)	1.69 (1.65,1.73)	< 0.001	
		Master's degree student or higher	28.23	2.82 (2.62,3.04)	2.77 (2.58,2.98)	< 0.001	
	2023	High school graduate or less	11.89	1.00	1.00	NA	< 0.001
		Studying in a 2-year college	12.65	1.01 (0.97,1.06)	1.01 (0.96,1.06)	0.689	
		Studying in a 3- to 4-year university	18.93	1.36 (1.31,1.40)	1.36 (1.32,1.40)	< 0.001	
		Master's degree student or higher	24.96	2.00 (1.86,2.15)	1.99 (1.85,2.15)	< 0.001	

Table 4. Prevalence of myopia and high myopia stratified by educational Level. [a] Unadjusted model. [b] Adjusted for BMI and urban index level. [c] P value from the Wald test (test of individual regression coefficients). [d] P value from the likelihood ratio test (comparison of model fit between Model 1 and Model 2).

	Exam year, y	Urban index level	Prevalence, %	Model 1 [a] Odds ratio (95%CI)	Model 2 [b] Odds ratio (95%CI)	*P* Value [c]	*P* Value [d]
Myopia	2011	Rural (0–40)	44.41	1.00	1.00	NA	< 0.001
		Sub-urban (41–80)	45.66	1.05 (1.00,1.11)	1.09 (1.03,1.14)	0.001	
		Urban (81–100)	51.29	1.32 (1.26,1.38)	1.34 (1.28,1.40)	< 0.001	
	2017	Rural (0–40)	47.62	1.00	1.00	NA	< 0.001
		Sub-urban (41–80)	50.56	1.12 (1.07,1.18)	1.13 (1.08,1.18)	< 0.001	
		Urban (81–100)	54.35	1.31 (1.25,1.37)	1.30 (1.25,1.36)	< 0.001	
	2023	Rural (0–40)	54.22	1.00	1.00	NA	< 0.001
		Sub-urban (41–80)	57.15	1.13 (1.06,1.19)	1.13 (1.07,1.20)	< 0.001	
		Urban (81–100)	60.24	1.28 (1.21,1.35)	1.27 (1.21,1.34)	< 0.001	
High Myopia	2011	Rural (0–40)	10.25	1.00	1.00	NA	< 0.001
		Sub-urban (41–80)	11.41	1.13 (1.04,1.22)	1.16 (1.07,1.26)	< 0.001	
		Urban (81–100)	14.72	1.51 (1.40,1.63)	1.52 (1.41,1.64)	< 0.001	
	2017	Rural (0–40)	11.78	1.00	1.00	NA	< 0.001
		Sub-urban (41–80)	13.22	1.14 (1.06,1.23)	1.15 (1.07,1.23)	< 0.001	
		Urban (81–100)	16.99	1.53 (1.44,1.64)	1.52 (1.42,1.62)	< 0.001	
	2023	Rural (0–40)	13.80	1.00	1.00	NA	< 0.001
		Sub-urban (41–80)	15.52	1.15 (1.06,1.25)	1.16 (1.07,1.26)	< 0.001	
		Urban (81–100)	18.02	1.37 (1.27,1.48)	1.37 (1.27,1.48)	< 0.001	

Table 5. Prevalence of myopia and high myopia stratified by urban index Level. [a] Unadjusted model. [b] Adjusted for BMI and years of education. [c] P value from the Wald test (test of individual regression coefficients). [d] P value from the likelihood ratio test (comparison of model fit between Model 1 and Model 2).

metropolitan area in spatial distribution maps for 2011 and 2023, and the prevalence of myopia and high myopia showed an increase across the entire nation during this period (Fig. 2). A small area in Gangwon Province also showed a high prevalence, which likely reflecting apparent variation due to unstable estimates from the small resident population.

Body stature
No consistent pattern was observed between BMI categories and the prevalence of myopia or high myopia (Supplementary Table 1). Although BMI showed statistically significant associations with myopia and high myopia in certain exam years, the direction and magnitude of these associations varied. Similarly, linear regression analysis revealed no correlation between SE and body stature supported by the low R-squared values (Supplementary Table 2).

Discussion
Our study is the largest population-based investigation to date of myopia prevalence and its risk factors including 4,063,091 19-year-old male participants examined over a 13-year period. This unprecedented dataset exceeds the scale of previous large cross-sectional studies in China, which typically included 1,013,206 children and adolescents or 1,323,052 adolescents, respectively[35,36]. Compared with a prior study in Korea that analyzed data from 2014 to 2020, our study's broader 13-year span from 2011 to 2023 provides a more comprehensive view of long-term trends in myopia prevalence[26]. The extended timeframe enabled us to identify more consistent patterns as well as evolving trends in the increasing prevalence of both myopia and high myopia, patterns that may not have been fully evident in shorter-term studies. We observed consistent increases in the prevalence of myopia and high myopia with rates rising from 50.6% to 14.3% in 2011 to 59.8% and 17.7% in 2023, respectively. Projection modeling further indicated that prevalence could reach approximately 84% for myopia and 28% for high myopia by 2050. These findings highlight not only the scale of the current burden but also the potential for a future escalation of the epidemic, underscoring the urgent need for preventive strategies.

While the 2011 prevalence of myopia in the current study was 50.58%, earlier research based on 19-year-old Korean male conscripts reported a substantially higher prevalence of myopia (96.5%) and high myopia (21.6%) in 2010[11]. This discrepancy may reflect sampling bias in the previous study, which included only residents of Seoul, the most urbanized and educated city in South Korea. By contrast, our analysis analyzed all 19-year-old conscripts nationwide to ensure a more representative estimate of myopia prevalence. In addition, the use of digital records in our study also enhanced data reliability compared with earlier paper-based surveys. We also applied district-level urban index classifications rather than broader province-level categories. The use of district-level data improved spatial precision in detecting myopia prevalence patterns and minimized misclassification caused by intra-provincial heterogeneity. To the best of our knowledge, this is the first large-scale study in South Korea to apply district-level measures of urbanization in the epidemiological analysis of myopia.

The current study confirmed a strong correlation between higher education levels and prevalence of both myopia and high myopia. Master's students or higher had significantly higher risk of myopia and high myopia compared to high school graduates or lower. Similarly, a meta-analysis in Europe reported that myopia (≤ −0.75

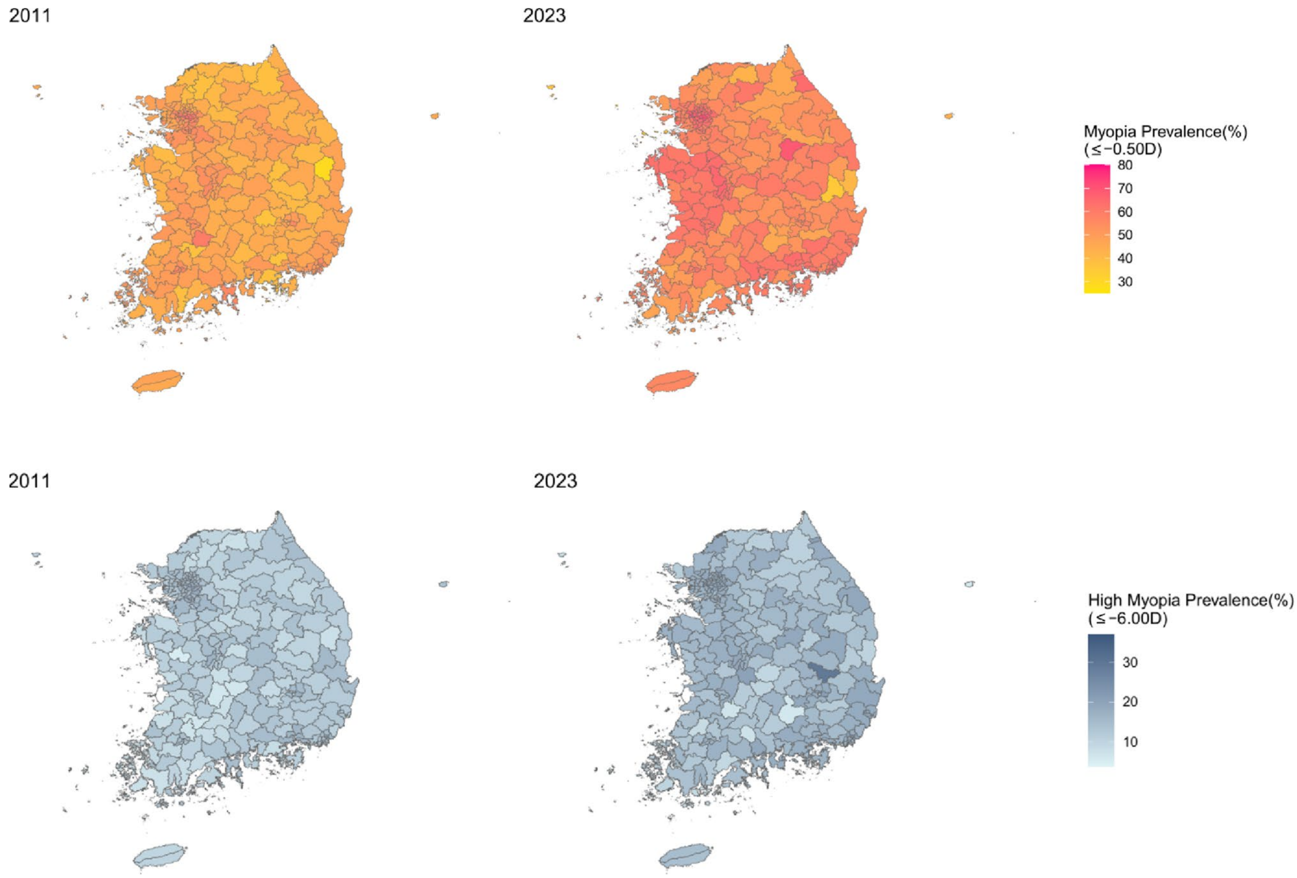

Fig. 2. Myopia and High Myopia Distribution in South Korea. Maps were generated by the authors using R version 4.2.2 with the sf and ggplot2 packages. Administrative boundary shapefiles were obtained from the Korean Open Government Data Portal (https://www.data.go.kr/data/15125045/fileData.do).

D) was twice as common among individuals who completed school at age ≥ 20 years compared to those who left school before age 16[37]. In a study on 17-year-old Israelis, participants who attained 12 years or more of education showed a higher prevalence of myopia (≤ −0.50 D) (27%) than those with only 1 to 6 years (10%)[38]. Education level is now widely accepted as a major risk factor for myopia, apparently due to academic pressure that extends near work and limits outdoor time[7,17]. Notably, our study revealed that the educational disparity in myopia has narrowed over the past decade. In 2011, the odds of myopia and high myopia were more than threefold higher in the most educated group compared with the least educated (OR = 3.20 and OR = 3.03, respectively), whereas by 2023 these disparities had decreased to approximately twofold (OR = 2.00 and OR = 1.99). Furthermore, no significant difference was observed between high school graduates and 2-year college students in 2023, suggesting that the epidemic is increasingly affecting groups previously. This narrowing disparity in myopia prevalence across educational groups may reflect lifestyle convergence, particularly the widespread and frequent use of smartphones among South Korean adolescents[39,40]. Given the established roles of intensive near work and insufficient outdoor exposure in driving myopia progression, these converging patterns likely contributed to the diminishing educational gradient observed in our study[41]. This underscores the need for comprehensive prevention strategies that address both digital device use and outdoor activity for the entire adolescent population.

The current study found that the risk of myopia and high myopia is notably higher in urban areas compared to rural areas ($P < 0.001$). This is consistent with a cross-sectional study in China, which randomly selected one district from each rural and urban region and showed a higher prevalence of myopia among urban (82.7%) compared to rural students (71.8%) after adjusting for age and gender[42]. Similarly, a longitudinal study in Taiwan showed higher rates of myopia in school-going children residing in urban areas compared with rural settings[43]. These consistent differences have been attributed to greater amount of time spent outdoors among children in rural environments, which is known to protect against myopia[19,44]. This finding indicates that outdoor activities may play a significant role in predicting and preventing the development of myopia and high myopia[44]. In contrast, a prior study in South Korea did not find a large difference in myopia between urban (Seoul, 96.5%) and rural areas (Jeju, 83.3%)[20]. This result may reflect limitations of the province-based classification used in that study, which could have underestimated the urbanization level in Jeju. In our study, we applied district-level urban index classifications to facilitate a more precise differentiation between rural and urban areas. This methodological refinement showed a clear urban–rural disparity in myopia prevalence in South Korea, consistent with findings from other East Asian countries.

Height, weight, and BMI were not significantly associated with myopia or high myopia in the present study. This observation is consistent with previous investigations conducted across different populations and age groups. A prior study in Beijing found that while higher BMI in children was associated with myopia and high myopia, the prevalence of severe high myopia was no longer significantly associated with body mass after adjustment for age ($P = 0.12$; OR = 1.03; 95% CI = 0.99–1.08)[22]. Similarly, an analysis of Danish conscripts found no association between BMI and myopia ($P = 0.883$)[23]. A nationwide study in Israel involving 106,926 participants also demonstrated that myopia was not related to either greater height or weight[45]. These results suggest that associations between body stature and myopia prevalence are inconsistent.

The prevalence of myopia and high myopia among young male conscripts in South Korea increased from 50.6% to 14.3% in 2011 to 59.8% and 17.7% in 2023, respectively over a decade. The consistent decline in median SE during this period suggests an earlier onset of myopia, which increases the likelihood of developing high myopia in adulthood[46]. The rapid rise in vision-threatening high myopia highlights an escalating public health concern, indicating that South Korea is facing a myopia epidemic. Similar increases have been presented elsewhere in East Asia. In China, the myopia prevalence in male high school students (mean age 18 years) rose from 78.3% in 2001 to 84.1% in 2015[8,12]. Myopia prevalence among 18-year-old Taiwanese high school students increased from 85.1% in 2005 to 90.3% in 2016[47].

Our projections further suggest that by 2050, if current trends persist, the prevalence of myopia and high myopia among 19-year-old males in South Korea will reach approximately 84% and 28%, respectively. These estimates are higher than global forecasts reported in a previous systematic review, which suggested that approximately 50% of the global population will be myopic by mid-century with East Asia expected to bear the greatest burden (65.3% in East Asia and 66.4% in the high-income Asia-Pacific region)[7]. A systematic review and meta-analysis projected a prevalence of 68.8% among Asian children and adolescents by 2050, and a study focused on China estimated that prevalence among adolescents aged 15–19 could reach 81.1% by the same period[48,49]. A recent population-based study restricted to male adolescents in Seoul projected a higher prevalence of myopia (90.9%) and high myopia (31.3%) by 2050, however, those estimates reflect exclusively the highly urbanized setting[25]. These findings reinforce expectations of continued sharp increases in myopia prevalence across East Asia, where adolescent prevalence is projected to reach or surpass 80% by mid-century.

Several countries with a high myopia burden have implemented national strategies to slow these trends[50]. In Taiwan, the national "Daily 120 Minutes Outdoors" program has reduced the trend of rising vision impairment among elementary school children in recent years[51]. Singapore's school-based National Myopia Prevention Program was associated with a significant reduction in myopia prevalence among primary school students, decreasing from 37.7% to 31.6% between 2004 and 2015[52]. China launched a comprehensive national children's myopia management plan in 2018 with specific local targets for myopia reduction[53]. However, South Korea currently has no national policies for myopia prevention. Given the predicted escalation in prevalence, especially in urbanized and academically intensive settings, there is a clear need for comprehensive, national strategies focused on prevention, early detection and control of myopia progression. To address the growing burden and delay disease onset, such strategies should prioritize school-based preventive interventions to maximize impact at the population level.

The present study has several limitations. First, only males were evaluated. While there are conflicting data regarding the influence of gender on myopia prevalence, previous studies have often shown higher myopia rates among young women and girls compared to men and boys[35,54,55]. This suggests that the overall population burden may be greater than our estimates. Second, this study employed non-cycloplegic autorefraction, which may lead to an overestimation of myopia prevalence compared with studies using cycloplegic refraction. For younger populations in non-cycloplegic settings, the International Myopia Institute recommends thresholds more negative than − 0.50 D to account for the risk of classification bias and potential false negatives[56]. Nevertheless, we applied the standard − 0.50 D criterion to maintain consistency with the thresholds employed in previous investigations. Third, refractive status was defined solely by SE values. Although this approach is widely adopted in population-based research, it may lead to misclassification of slightly hyperopic eyes as myopic because of the averaging effect inherent to the SE formula. However, according to national survey data, the prevalence of hyperopia (SE > + 0.5D) among Koreans aged 12–18 and 19–29 was 2.6% and 2.2%, respectively[57], indicating that the potential overestimation of the myopia due to the SE-based classification is likely minimal. Furthermore, similar methodology has been consistently applied in previous studies using the same database, supporting meaningful comparison and the validity of the findings. Fourth, educational level was determined through automatic linkage to the national education database, which may have underestimated master's degree enrollment, particularly among individuals assessed in the most recent four years. As the database is updated annually, participants who had not yet entered graduate programs at the time of data retrieval may have been misclassified into lower categories. In contrast, for individuals examined before 2020, the recorded educational level is more likely to reflect their final academic attainment. Fifth, key behavioral and environmental risk factors such as parental history of myopia, duration of near work and exposure to outdoor light were not available in the database. These unmeasured variables are known to influence the development and progression of myopia and could not be accounted for in our analysis due to data constraints. Lastly, individuals exempted from compulsory military service or physical examination were not available in the database. However, this group represents an extremely small proportion of the population, and the potential impact on our findings is likely negligible.

In conclusion, this study provides the largest and most comprehensive population-based analysis of myopia trends and associated risk factors to date. Utilizing 13 years of nationally representative conscription data, we demonstrated a steady rise in both myopia and high myopia with increasing prevalence even among groups previously considered at lower risk, indicating a broadening impact of the myopia epidemic across all sociodemographic strata. Projection modeling further suggests that by 2050, prevalence may reach approximately 84% for myopia and 28% for high myopia in this population. These findings highlight an urgent public health challenge and underscore the need for a coordinated national strategy in South Korea, incorporating timely optical correction, evidence-based preventive interventions and targeted public awareness initiatives to mitigate the escalating burden of myopia given the current absence of national preventive policies.

Data availability

The data that support the findings of this study are available from Military Manpower Administration of the Republic of Korea, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Military Manpower Administration of the Republic of Korea.

Received: 30 April 2025; Accepted: 8 December 2025
Published online: 15 December 2025

References

1. World Health Organization. World report on vision. (World Health Organization & Geneva ISBN: 978-92-4-151657-0. (2019). Available at: https://www.who.int/publications/i/item/world-report-on-vision
2. Haarman, A. E. G. et al. The complications of myopia: A review and Meta-Analysis. *Invest. Ophthalmol. Vis. Sci.* **61**, 49. https://doi.org/10.1167/iovs.61.4.49 (2020).
3. Naidoo, K. S. et al. Potential lost productivity resulting from the global burden of myopia: systematic Review, Meta-analysis, and modeling. *Ophthalmology* **126**, 338–346. https://doi.org/10.1016/j.ophtha.2018.10.029 (2019).
4. Modjtahedi, B. S., Ferris, F. L. 3, Hunter, D. G., Fong, D. S. & rd, & Public health burden and potential interventions for myopia. *Ophthalmology* **125**, 628–630. https://doi.org/10.1016/j.ophtha.2018.01.033 (2018).
5. Burton, M. J. et al. The lancet global health commission on global eye health: vision beyond 2020. *Lancet Glob Health*. **9**, e489–e551. https://doi.org/10.1016/s2214-109x(20)30488-5 (2021).
6. Bourne, R. R. A. et al. Magnitude, Temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta-analysis. *Lancet Glob Health*. **5**, e888–e897. https://doi.org/10.1016/s2214-109x(17)30293-0 (2017).
7. Holden, B. A. et al. Global prevalence of myopia and high myopia and Temporal trends from 2000 through 2050. *Ophthalmology* **123**, 1036–1042. https://doi.org/10.1016/j.ophtha.2016.01.006 (2016).
8. Chen, M. et al. The increasing prevalence of myopia and high myopia among high school students in Fenghua city, Eastern china: a 15-year population-based survey. *BMC Ophthalmol.* **18**, 159. https://doi.org/10.1186/s12886-018-0829-8 (2018).
9. Rudnicka, A. R. et al. Global variations and time trends in the prevalence of childhood myopia, a systematic review and quantitative meta-analysis: implications for aetiology and early prevention. *Br. J. Ophthalmol.* **100**, 882–890. https://doi.org/10.1136/bjophthalmol-2015-307724 (2016).
10. Morgan, I. G., Ohno-Matsui, K., Saw, S. M. & Myopia *Lancet* **379**, 1739–1748 https://doi.org/10.1016/S0140-6736(12)60272-4 (2012).
11. Jung, S. K., Lee, J. H., Kakizaki, H. & Jee, D. Prevalence of myopia and its association with body stature and educational level in 19-year-old male conscripts in seoul, South Korea. *Invest. Ophthalmol. Vis. Sci.* **53**, 5579–5583. https://doi.org/10.1167/iovs.12-10106 (2012).
12. Koh, V. et al. Differences in prevalence of refractive errors in young Asian males in Singapore between 1996–1997 and 2009–2010. *Ophthalmic Epidemiol.* **21**, 247–255. https://doi.org/10.3109/09286586.2014.928824 (2014).
13. Lin, L. L., Shih, Y. F., Hsiao, C. K. & Chen, C. J. Prevalence of myopia in Taiwanese schoolchildren: 1983 to 2000. *Ann. Acad. Med. Singap.* **33**, 27–33 (2004).
14. Wu, J. F. et al. Refractive error, visual acuity and causes of vision loss in children in Shandong, China. The Shandong children eye study. *PLoS One*. **8**, e82763. https://doi.org/10.1371/journal.pone.0082763 (2013).
15. Xiang, F. et al. Increases in the prevalence of reduced visual acuity and myopia in Chinese children in Guangzhou over the past 20 years. *Eye (Lond)*. **27**, 1353–1358. https://doi.org/10.1038/eye.2013.194 (2013).
16. Wen, G. et al. Prevalence of Myopia, Hyperopia, and astigmatism in Non-Hispanic white and Asian children: Multi-Ethnic pediatric eye disease study. *Ophthalmology* **120**, 2109–2116. https://doi.org/10.1016/j.ophtha.2013.06.039 (2013).
17. Morgan, I. G. et al. The epidemics of myopia: aetiology and prevention. *Prog Retin Eye Res.* **62**, 134–149. https://doi.org/10.1016/j.preteyeres.2017.09.004 (2018).
18. Pan, C. W., Ramamurthy, D. & Saw, S. M. Worldwide prevalence and risk factors for myopia. *Ophthalmic Physiol. Opt.* **32**, 3–16. https://doi.org/10.1111/j.1475-1313.2011.00884.x (2012).
19. Guo, Y. et al. Outdoor activity and myopia among primary students in rural and urban regions of Beijing. *Ophthalmology* **120**, 277–283. https://doi.org/10.1016/j.ophtha.2012.07.086 (2013).
20. Lee, J. H., Jee, D., Kwon, J. W. & Lee, W. K. Prevalence and risk factors for myopia in a rural Korean population. *Invest. Ophthalmol. Vis. Sci.* **54**, 5466–5471. https://doi.org/10.1167/iovs.13-12478 (2013).
21. Cheng, H. C., Chang, K., Shen, E., Luo, K. S. & Ying, Y. H. Risk factors and behaviours of schoolchildren with myopia in Taiwan. *Int. J. Environ. Res. Public. Health*. **17** https://doi.org/10.3390/ijerph17061967 (2020).
22. Guo, Y. et al. High myopia in greater Beijing school children in 2016. *PLoS One*. **12**, e0187396. https://doi.org/10.1371/journal.pone.0187396 (2017).
23. Jacobsen, N., Jensen, H. & Goldschmidt, E. Prevalence of myopia in Danish conscripts. *Acta Ophthalmol. Scand.* **85**, 165–170. https://doi.org/10.1111/j.1600-0420.2006.00789.x (2007).
24. Sharma, A. et al. Height, stunting, and refractive error among rural Chinese schoolchildren: the see well to learn well project. *Am. J. Ophthalmol.* **149**, 347–353e341. https://doi.org/10.1016/j.ajo.2009.08.015 (2010).
25. Surl, D., Seo, Y. & Han, J. Trends in myopia prevalence among late adolescents in South korea: a population-level study and future projections up to 2050. *BMJ Open. Ophthalmol.* **9** https://doi.org/10.1136/bmjophth-2024-001748 (2024).
26. Gwon, S. H. & Lee, D. C. Factors associated with myopia in 19-year-old adult men in Korea between 2014 and 2020. *Sci. Rep.* **13**, 11581. https://doi.org/10.1038/s41598-023-38569-w (2023).
27. Republic of Korea. Military Service Act, Article 11 (Draft Physical Examination). Korean Law Information Center, Ministry of Government Legislation. https://www.law.go.kr/LSW/eng/engLsSc.do?menuId=2&section=lawNm&query=military+act&x=0&y=0#liBgcolor7. Accessed 26 Nov 2025.
28. Ministry of the Interior and Safety. Current Status of Registered Population: Registered Population by Administrative District. *KOSIS (Korean Statistical Information Service)* June (2024). https://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1B04006&conn_path=I2 (2011–2023). Accessed 3.
29. Military Manpower Administration. Military Statistics: Military Service Examination Status – By Service Type, by District (19 Years). *KOSIS (Korean Statistical Information Service)* June (2024). https://kosis.kr/statHtml/statHtml.do?orgId=144&tblId=TX_14401_A007&conn_path=I2 (2011–2023). Accessed 3.

30. Ministry of National Defense. Rules for Physical Examination and Other Examinations for Military Service Determination, No. 1139. *Korea Law Information Center* (2024). -02-01 https://www.law.go.kr/LSW/lsRvsDocListP.do?chrClsCd=010102&lsId=008404 Accessed 3 June 2024.
31. World Health Organization Regional Office for the Western Pacific. The Asia-Pacific perspective: redefining obesity and its treatment. Health Communications Australia, Sydney. (2000). Available at: http://iris.wpro.who.int/handle/10665.1/5379. Accessed 3 June 2024.
32. WHO Expert Consultation. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet* **363**, 157–163. https://doi.org/10.1016/S0140-6736(03)15268-3 (2004).
33. Statistics Korea. *Population: households and housing units.* June (2024). https://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1IN1502&conn_path=I2&language=en (2011–2023). Accessed 3.
34. Korea, L. June & Housing Corporation. *Urban planning status: population status in urban areas (cities, counties, and districts).* (2024). https://kosis.kr/statHtml/statHtml.do?orgId=460&tblId=TX_315_2009_H1001&conn_path=I2 (2011–2023). Accessed 3.
35. Zhang, J. et al. Prevalence of myopia: A large-scale population-based study among children and adolescents in weifang, China. *Front. Public. Health.* **10**, 01–10. https://doi.org/10.3389/fpubh.2022.924566 (2022).
36. Peled, A. et al. Myopia and BMI: a nationwide study of 1.3 million adolescents. *Obes. (Silver Spring).* **30**, 1691–1698. https://doi.org/10.1002/oby.23482 (2022).
37. Williams, K. M. et al. Increasing prevalence of myopia in Europe and the impact of education. *Ophthalmology* **122**, 1489–1497. https://doi.org/10.1016/j.ophtha.2015.03.018 (2015).
38. Shapira, Y. et al. The increasing burden of myopia in Israel among young adults over a generation: analysis of predisposing factors. *Ophthalmology* **126**, 1617–1626. https://doi.org/10.1016/j.ophtha.2019.06.025 (2019).
39. Lee, K. E. et al. Dependency on smartphone use and its association with anxiety in Korea. *Public. Health Rep.* **131**, 411–419. https://doi.org/10.1177/003335491613100307 (2016).
40. Lee, J. Effect of Loneliness and Depressive Symptoms on Smartphone Overdependence among South Korean Adolescents: A Nationwide Cross-Sectional Study. *kjhp* 22, 1–9 (2022). https://doi.org/10.15384/kjhp.2022.22.1.1
41. Biswas, S. et al. The influence of the environment and lifestyle on myopia. *J. Physiol. Anthropol.* **43**, 7. https://doi.org/10.1186/s40101-024-00354-7 (2024).
42. Wang, Y. et al. Rural-urban differences in prevalence of and risk factors for refractive errors among school children and adolescents aged 6–18 years in Dalian, China. *Front. Public. Health.* **10**, 917781. https://doi.org/10.3389/fpubh.2022.917781 (2022).
43. Wu, P. C., Tsai, C. L., Hu, C. H. & Yang, Y. H. Effects of outdoor activities on myopia among rural school children in Taiwan. *Ophthalmic Epidemiol.* **17**, 338–342. https://doi.org/10.3109/09286586.2010.508347 (2010).
44. He, M. et al. Effect of time spent outdoors at school on the development of myopia among children in china: A randomized clinical trial. *JAMA* **314**, 1142–1148. https://doi.org/10.1001/jama.2015.10803 (2015).
45. Rosner, M., Laor, A. & Belkin, M. Myopia and stature: findings in a population of 106,926 males. *Eur. J. Ophthalmol.* **5**, 1–6 (1995).
46. Hu, Y. et al. Association of age at myopia onset with risk of high myopia in adulthood in a 12-Year Follow-up of a Chinese cohort. *JAMA Ophthalmol.* **138**, 1129–1134. https://doi.org/10.1001/jamaophthalmol.2020.3451 (2020).
47. Tsai, T. H. et al. Evolution of the prevalence of myopia among Taiwanese schoolchildren: A review of survey data from 1983 through 2017. *Ophthalmology* **128**, 290–301. https://doi.org/10.1016/j.ophtha.2020.07.017 (2021).
48. Liang, J. et al. Global prevalence, trend and projection of myopia in children and adolescents from 1990 to 2050: a comprehensive systematic review and meta-analysis. *Br. J. Ophthalmol.* **109**, 362–371. https://doi.org/10.1136/bjo-2024-325427 (2025).
49. Pan, W. et al. Prevalence and Temporal trends in myopia and high myopia children in china: a systematic review and meta-analysis with projections from 2020 to 2050. *Lancet Reg. Health – Western Pac.* **55** https://doi.org/10.1016/j.lanwpc.2025.101484 (2025).
50. Morgan, I. G. & Jan, C. L. China turns to school reform to control the myopia epidemic: A narrative review. *Asia-Pacific J. Ophthalmol.* **11**, 27–35. https://doi.org/10.1097/apo.0000000000000489 (2022).
51. Wu, P. C. et al. Increased time outdoors is followed by reversal of the Long-Term trend to reduced visual acuity in Taiwan primary school students. *Ophthalmology* **127**, 1462–1469. https://doi.org/10.1016/j.ophtha.2020.01.054 (2020).
52. Karuppiah, V., Wong, L., Tay, V., Ge, X. & Kang, L. L. School-based programme to address childhood myopia in Singapore. *Singap. Med. J.* **62**, 63–68. https://doi.org/10.11622/smedj.2019144 (2021).
53. Jan, C. L. & Congdon, N. Chinese National policy initiative for the management of childhood myopia. *Lancet Child. Adolesc. Health.* **2**, 845–846. https://doi.org/10.1016/S2352-4642(18)30318-3 (2018).
54. Wu, L. J. et al. Prevalence and associated factors of myopia in High-School students in Beijing. *PLOS ONE.* **10**, e0120764. https://doi.org/10.1371/journal.pone.0120764 (2015).
55. Czepita, M., Czepita, D. & Safranow, K. Role of gender in the prevalence of myopia among Polish schoolchildren. *J. Ophthalmol.* **2019**, 1–4. https://doi.org/10.1155/2019/9748576 (2019).
56. Flitcroft, D. I. et al. IMI - Defining and classifying myopia: A proposed set of standards for clinical and epidemiologic studies. *Invest. Ophthalmol. Vis. Sci.* **60**, M20–m30. https://doi.org/10.1167/iovs.18-25957 (2019).
57. Rim, T. H. et al. Refractive errors in koreans: the Korea National health and nutrition examination survey 2008–2012. *Korean J. Ophthalmol.* **30**, 214–224. https://doi.org/10.3341/kjo.2016.30.3.214 (2016).

Author contributions

K. S. and S. Y contributed to research design. Y. L., J. L., and D. A. were responsible for data acquisition. Y. L. and S. Y. were involved in data analysis and interpretation. Y. L., S. Y, and N. C. contributed to manuscript preparation.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-32048-0.

Correspondence and requests for materials should be addressed to S.Y.

Reprints and permissions information is available at www.nature.com/reprints.