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Determinants of Refractive Error Among School-Going Children in North India: A Machine Learning-Enhanced Analysis Using Elastic Net Regression

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Abstract:

Background: Refractive error is a leading cause of visual impairment among school-aged children globally, yet population-specific determinants remain inadequately characterized in resource-limited settings.

Objective: This study sought to quantify the prevalence of refractive error and develop predictive models identifying sociodemographic, environmental, dietary, and behavioral determinants among school-going children in Mathura, Uttar Pradesh.

Methods: A cross-sectional study was conducted among 2,000 school children aged 6-16 years. Comprehensive vision screening was performed, and data on sociodemographic characteristics, housing conditions, dietary patterns, lifestyle factors, and academic variables were collected through structured questionnaires. Multivariable logistic regression and elastic net regularized regression were used to identify independent predictors of refractive error.

Results: The prevalence of refractive error was 24.1% (482/2,000). In multivariable analysis, urban residence (adjusted OR 1.71, 95% CI: 1.31-2.22, p<0.001) and increasing age (adjusted OR 1.14 per year, 95% CI: 1.08-1.21, p<0.001) were the strongest independent predictors. Weekly intake of green leafy vegetables showed a modest positive association (adjusted OR 1.43, 95% CI: 1.07-1.93, p=0.018). Socioeconomic status, parental education, nutritional status, anemia, screen time, and sleep duration were not significantly associated with refractive error after adjustment. Elastic net regression confirmed age (OR 1.20), class grade (OR 1.17), and urban residence (OR 1.15) as primary drivers.

Conclusions: Refractive error among school children in this population is predominantly influenced by age and urban residence rather than traditional socioeconomic or nutritional factors. These findings emphasize the need for strengthened school-based vision screening programs, particularly targeting older children in urban settings, and highlight the role of environmental and behavioral exposures in refractive error development.

Keywords: Refractive error, school children, urban health, screening

I. INTRODUCTION

Refractive error is one of the most common but preventable causes of vision problems in children around the world. The World Health Organization estimates that nearly 19 million children have visual impairments globally[1]. A significant part of this issue comes from uncorrected refractive errors. Among school-aged children, untreated refractive error has been linked to poorer academic performance, lower quality of life, and fewer job opportunities in the future. The prevalence of refractive error varies greatly based on geography and demographic.[2] Research from East and Southeast Asia shows concerning increases in myopia rates among children, with some urban areas reporting rates over 80%. In contrast, data from South Asia, especially India, is often inconsistent and relies on hospital-based or limited community studies. Understanding the factors that affect refractive error is essential. [3–5]Knowing what influences refractive error in

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different contexts is crucial for developing effective public health strategies and properly allocating resources for school health programs. Common risk factors for refractive error include genetic traits, extensive near-vision tasks, long screen time, lack of outdoor activities, and specific environmental influences. [6]However, the effects of socioeconomic status, nutrition, living conditions, and educational qualities are still not well understood, especially in communities experiencing rapid urban growth and educational changes. Previous studies have suggested a possible link between refractive error and signs of socioeconomic development. [7]Refractive error in children has been linked to urban residence, private schooling, and better housing, possibly reflecting behavioral and environmental factors such as higher academic pressure, reduced outdoor activity, and greater screen exposure. However, few studies have comprehensively assessed the independent roles of demographic, socioeconomic, nutritional, behavioral, and educational factors together. India's rapidly urbanizing and educationally expanding population provides a unique context to explore these relationships. This study was conducted to estimate the prevalence of refractive error and explore its sociodemographic, environmental, dietary, and behavioral determinants through statistical modeling among school-going children aged 6–16 years in Mathura, Uttar Pradesh.

II. METHODOLOGY

This cross-sectional study was conducted over 1.5 years (2023-2024) and included 2,000 school-going children aged 6–16 years from rural and urban areas of Mathura, Uttar Pradesh. Written informed consent was obtained from parents or guardians of all participating children prior to enrollment.Using multistage cluster sampling, government, aided, and private schools were selected with probability proportional to size. Data were collected using a self-structured questionnaire that was validated by subject matter experts to ensure content validity and reliability. Visual acuity was assessed using Snellen charts for distance vision at 6 meters and standard near vision charts for near vision assessment. Children with visual acuity worse than 6/9 in either eye underwent detailed refraction using retinoscopy followed by subjective refinement. Refractive error was defined as myopia (≤-0.50 D), hypermetropia (≥+2.00 D), or astigmatism (≥1.00 D cylindrical power) in either eye.

III. STATISTICAL ANALYSIS

Data were analyzed using R statistical software (version 4.0). Categorical variables were expressed as frequencies and percentages. Chi-square tests assessed bivariate associations between predictor variables and refractive error. Multivariable logistic regression identified independent predictors of refractive error. All variables that showed an association with refractive error at $p<0.20$ in bivariate analysis were included in the initial model. Backward elimination was used, keeping variables significant at $p<0.05$ or those deemed important. Results were reported as adjusted odds ratios with 95% confidence intervals. To address possible multicollinearity and improve model stability, elastic net regularized logistic regression was conducted. The optimal tuning parameters (alpha and lambda) were chosen through 10-fold cross-validation. Variables with non-zero coefficients in the final elastic net model were identified as important predictors. Forest plots were generated to visually display effect estimates and confidence intervals from the multivariable logistic regression model. All statistical tests were two-tailed, and $p<0.05$ was considered statistically significant.

IV. RESULTS

The study included 2,000 school children aged 6-16 years (median age 10.5 years, IQR 7.0-14.0). The sample comprised 953 females (47.7%) and 1,047 males (52.3%). Urban children represented 34.9% (698) of the sample, while 65.1% (1,302) resided in rural areas. The overall prevalence of refractive error was 24.1% (482/2,000; 95% CI: 22.3-26.0%).
Children with refractive errors were significantly older (median 13.0 years, IQR 9.0-15.0) compared to those without refractive errors (median 10.0 years, IQR 7.0-14.0; p<0.001). Urban children had significantly higher prevalence (31.7%, 221/698) than rural children (20.0%, 261/1,302; p<0.001).

Table 1. Baseline Characteristics and Bivariate Associations with Refractive Error

Characteristic	No RE N=1,518 (%)	RE Present N=482 (%)	p-value
Residence			<0.001
Rural	1,041 (68.6)	261 (54.1)	
Urban	477 (31.4)	221 (45.9)	
Age (years), median (IQR)	10.0 (7.0, 14.0)	13.0 (9.0, 15.0)	<0.001
Gender			0.6

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Female	728 (48.0)	225 (46.7)	
Male	790 (52.0)	257 (53.3)	
Class Grade			<0.001
Secondary (6-8)	790 (52.0)	160 (33.2)	
High School (9-12)	728 (48.0)	322 (66.8)	
Socioeconomic Status			0.6
Low	693 (45.7)	216 (44.8)	
Medium	611 (40.3)	189 (39.2)	
High	214 (14.1)	77 (16.0)	
Type of School			<0.001
Government	901 (59.4)	236 (49.0)	
Private	472 (31.1)	198 (41.1)	
Aided	145 (9.6)	48 (10.0)	
House Type			0.003
Kutcha	302 (19.9)	86 (17.8)	
Semi-Pucca	561 (37.0)	146 (30.3)	
Pucca	655 (43.1)	250 (51.9)	
Clean Fuel Use	973 (64.1)	349 (72.4)	<0.001
Green Leafy Vegetable Intake			0.026
Daily	319 (21.0)	81 (16.8)	
Rarely	530 (34.9)	157 (32.6)	
Weekly	669 (44.1)	244 (50.6)	
Sleep Duration			0.006
Adequate (≥8 hours)	994 (65.5)	282 (58.5)	
Inadequate (<8 hours)	524 (34.5)	200 (41.5)	
Screen Time (>90 min/day)	1,190 (78.4)	387 (80.3)	0.4
Malnutrition (WHZ<-2)	881 (58.0)	282 (58.5)	0.9
Anemia (Hb<11.5 g/dL)	1,163 (76.6)	372 (77.2)	0.8

RE = Refractive Error; IQR = Interquartile Range; WHZ = Weight-for-Height Z-score; Hb = Hemoglobin. P-values from Pearson's chi-square test or Wilcoxon rank-sum test.

Table 2 shows multivariable logistic regression analysis adjusting for all potential confounders, urban residence and increasing age emerged as the strongest independent predictors of refractive error. Weekly intake of green leafy vegetables showed a modest positive association. Variables not significantly associated after adjustment included socioeconomic status, parental education, house type, clean fuel use, school type, nutritional status, anemia, screen time, and sleep duration.

Table 2. Multivariable Logistic Regression Analysis of Refractive Error Determinants

Variable	**Adjusted OR**	**95% CI**	**p-value**
Urban residence (vs Rural)	1.71	1.31-2.22	<0.001
Age (per year increase)	1.14	1.08-1.21	<0.001
Green leafy vegetables			
Daily	---	—	—
Rarely	1.16	0.85-1.59	0.4
Weekly	1.43	1.07-1.93	0.018
Non-significant associations:			
Gender (Male vs Female)	1.10	0.89-1.37	0.4

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Socioeconomic status (Low vs High)	0.82	0.60-1.13	0.2
School type (Government vs Aided)	0.66	0.44-1.01	0.053
Clean fuel use (Yes vs No)	1.17	0.91-1.51	0.2
Screen time (>90 min vs ≤90 min)	0.90	0.68-1.19	0.5
Sleep (Inadequate vs Adequate)	1.06	0.84-1.33	0.6
Malnutrition (Yes vs No)	1.04	0.83-1.30	0.7
Anemia (Yes vs No)	1.01	0.78-1.31	>0.9

OR = Odds Ratio; CI = Confidence Interval;

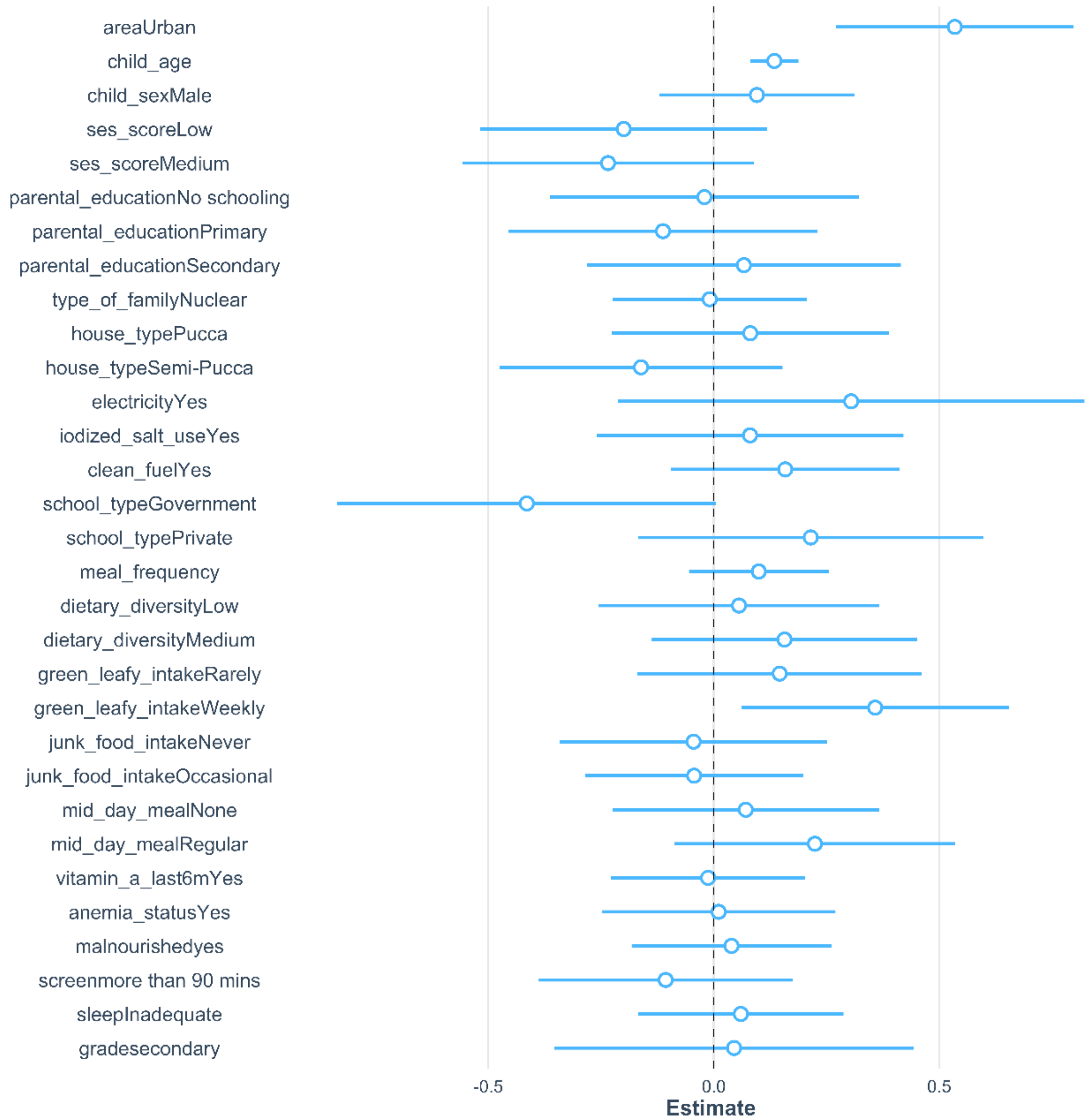

Figure1 Forest Plot of logistic regression

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The forest plot visually depicts the direction and strength of association between multiple sociodemographic, dietary, and environmental factors and refractive error after multivariable adjustment. The horizontal confidence intervals allow rapid comparison of effect sizes across variables, with the vertical reference line indicating no association.

The figure clearly demonstrates that urban residence and increasing age are the only variables showing a consistent and statistically meaningful association, as their confidence intervals lie entirely to the right of the null line. Most other predictors cluster closely around the null value, indicating weak or no independent association after adjustment.

Importantly, the plot highlights the overall stability of estimates, with relatively narrow confidence intervals for most variables, suggesting good model precision. Factors related to socioeconomic status, diet, housing conditions, and health indicators show overlapping confidence intervals with the null, visually reinforcing their limited contribution once confounding is controlled.

Overall, the forest plot complements the regression table by providing an intuitive visual summary of effect direction and magnitude, emphasizing that refractive error in this population is primarily associated with age and urban residence rather than nutritional or household factors.

Elastic Net Regression

Table 3 Elastic Net Regression Findings

	term	log_odds	OR
1	child_age	0.183038194	1.2008603
2	class_grade	0.159065774	1.1724151
3	area.Urban	0.139447146	1.1496380
4	green_leafy_intake.Weekly	0.094567675	1.0991835
5	screen_time_hr	0.084637364	1.0883223
6	school_type.Government	-0.078466352	0.9245332
7	clean_fuel.Yes	0.066472141	1.0687312
8	sleep_hours	-0.044116269	0.9568427
9	school_type.Private	0.036136157	1.0367970
10	house_type.Semi-Pucca	-0.035889255	0.9647471
11	house_type.Pucca	0.035739470	1.0363858
12	mid_day_meal.None	0.030723820	1.0312007
13	electricity.Yes	0.029600563	1.0300430
14	dietary_diversity.Medium	0.023212503	1.0234840
15	child_age:child_sexMale	0.022091156	1.0223370
16	parental_education.Primary	-0.009672487	0.9903741
17	junk_food_intake.Occasional	-0.006004883	0.9940131

An elastic net–regularized logistic regression model was fitted to identify independent predictors of refractive error while accounting for multicollinearity and high inter-correlation among explanatory variables. The elastic net approach, which combines both LASSO and ridge penalties, enables stable coefficient estimation while simultaneously performing variable selection. The elastic net analysis confirms that age, urban residence, and class grade are the most robust predictors of refractive error, as these variables survived the regularization penalty. Screen time, sleep duration, and weekly green leafy vegetable intake showed weak but non-zero effects. The model retained a limited number of predictors with non-zero coefficients, indicating that only a subset of variables contributed meaningfully to refractive error risk after regularization.

Age was the strongest predictor of refractive error, with each unit increase associated with a 20% higher odds (OR = 1.20), followed by class grade (OR = 1.17), urban residence (OR = 1.15), and screen time (OR = 1.09), while longer sleep duration showed a modest protective effect (OR = 0.96). Socioeconomic, dietary, and housing variables showed only weak associations such as green leafy vegetable intake (OR = 1.09), government school attendance (OR = 0.92), semi-pucca housing (OR = 0.96), and clean fuel use (OR = 1.07)indicating that refractive error in this population is driven primarily by age-related, educational, and behavioral factors, as robustly identified using the elastic net model.

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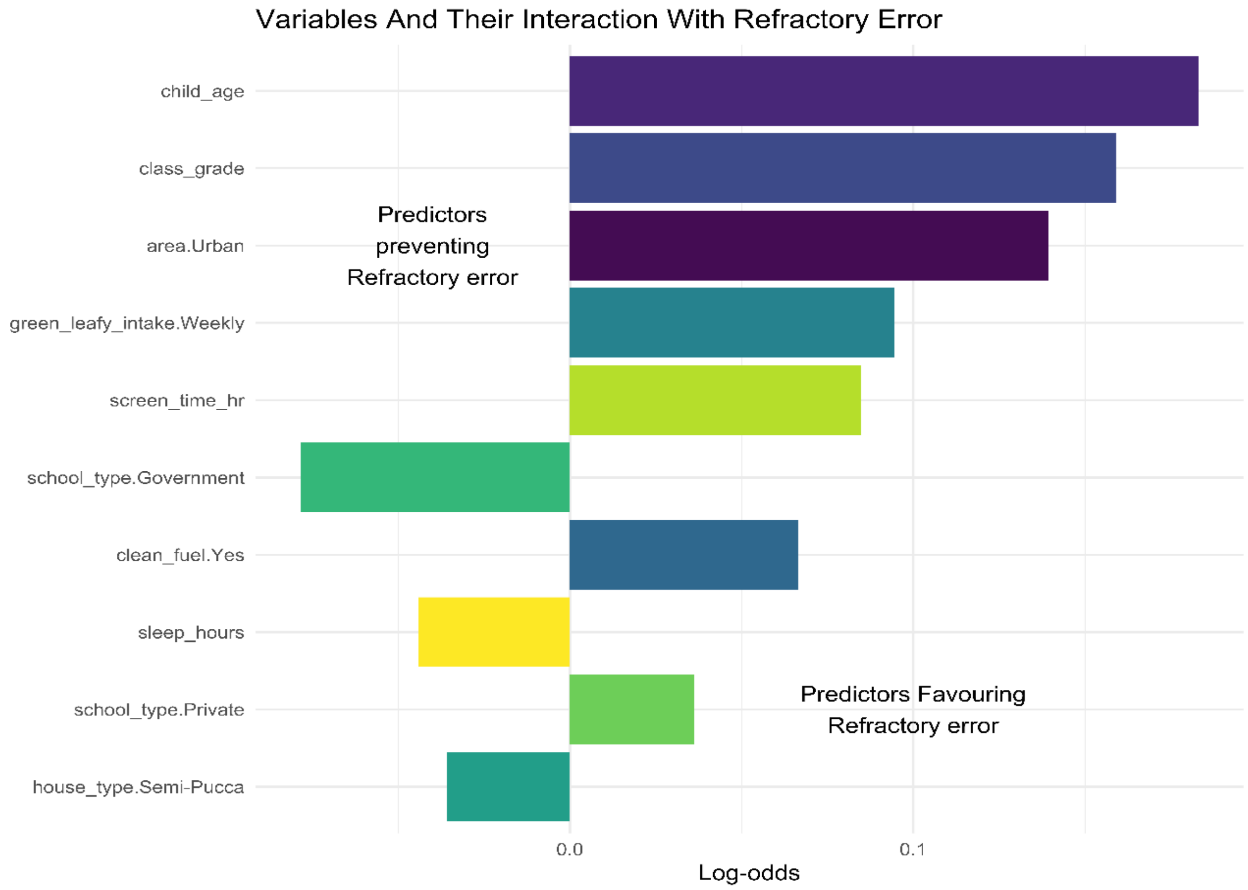

Figure 2 Elastic Net Coefficient Plot

Figure 2 illustrates the relative contribution of selected predictors to refractive error based on the Elastic Net regression model, expressed as standardized log-odds. Only variables with non-zero coefficients are shown, indicating their independent contribution after penalization and variable selection.

Age emerged as the strongest predictor, with increasing age showing the highest positive association with refractive error. This was followed by class grade and urban residence, reinforcing the role of academic exposure and urban lifestyle factors in the development of refractive errors. Screen time and weekly consumption of green leafy vegetables also demonstrated positive associations, though with smaller effect sizes, suggesting lifestyle and behavioral influences rather than direct causality.

Among protective factors, attendance at government schools and longer sleep duration showed negative coefficients, indicating a potential protective effect against refractive error. Semi-pucca housing also demonstrated a weak inverse association, likely reflecting broader socioeconomic or environmental influences rather than a direct protective mechanism.

Overall, the plot highlights that age, schooling-related factors, and urban living patterns are the dominant drivers of refractive error, while nutritional and household factors play a comparatively smaller role after adjustment. The elastic net model thus supports the findings of the multivariable logistic regression while providing a more parsimonious and robust identification of key predictors.

V. DISCUSSION

This cross-sectional study of 2,000 school-aged children in Mathura, Uttar Pradesh revealed a refractive error prevalence of 24.1%, with urban residence and increasing age emerging as the predominant independent determinants. Contrary to conventional assumptions, socioeconomic status, parental education, nutritional status, anaemia, and most lifestyle factors demonstrated no significant independent association with refractive error after multivariable adjustment.

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The observed prevalence of 24.1% aligns with recent estimates from India but varies considerably from international data. Studies in urban India report prevalence ranging from 21% to 35%, while rural estimates typically fall between 7% and 15%.[8,9]Our finding of relatively balanced rural and urban representation in the sample, though with substantially higher burden in urban children, suggests that aggregate prevalence figures may obscure important geographic disparities. Compared to East Asian populations, where myopia rates frequently exceed 60-80% among urban adolescents, our estimates remain substantially lower.[10]

Urban residence emerged as the strongest predictor of refractive error, with children in urban settings demonstrating 71% higher odds of refractive error compared to rural counterparts, even after adjusting for socioeconomic status, school type, and housing conditions. This robust association persists despite controlling for potential confounders that might differentiate urban from rural environments, suggesting that urbanicity itself likely confers direct risk through environmental and behavioral mechanisms. Several plausible explanations merit consideration. Urban children typically experience reduced outdoor time due to limited safe play spaces, traffic congestion, and increased engagement in indoor activities.Research has demonstrated similar findings.[11] Outdoor time has been consistently demonstrated to confer protection against myopia development, likely through increased retinal dopamine release and modulation of axial eye growth. Urban environments may additionally expose children to greater artificial light exposure, circadian disruption, and elevated visual demands from near-work activities. Furthermore, children in urban settings may have greater access to and utilization of digital devices for both educational and recreational purposes. While screen time did not demonstrate significant association in our multivariable model, this may reflect measurement limitations rather than absence of effect. The elastic net model identified screen time as a contributing factor to refractive error risk, suggesting it should not be dismissed entirely.

The marked age-related increase in refractive error, with 14% increase in odds per year of age, is consistent with established patterns of myopia progression during school years. This likely reflects cumulative exposure to near-work, ongoing ocular growth, and escalating academic demands as children advance through successive grades. The persistence of age effects even after adjustment for class grade suggests that biological factors associated with age play a role beyond mere educational environment. The elastic net model identified both age and class grade as independent predictors, implying that they influence refractive error through distinct pathways. Age may reflect biological maturation and cumulative near-work exposure over time, while class grade may capture current academic load and visual behaviors.Previous studies have reported comparable results.[12] This underscores the importance of both developmental stage and contemporaneous environmental exposures in refractive error pathogenesis.

We observed no independent associations with socioeconomic status, parental education, nutritional status or anaemia. However, research by Badmus et al. shows that higher individual and parental levels of education are significantly associated with an increased tendency toward myopia in a young adult Nigerian population.[13]

This suggests that refractive error in contemporary Indian children is increasingly driven by environmental and behavioral factors rather than nutritional deficiencies or poverty. The unanticipated positive association between weekly green leafy vegetable consumption and refractive error likely represents residual confounding by socioeconomic status or educational factors rather than a causal relationship.The study by Zhaoxia Xu indicates a possible link between nutritional factors and myopia among adolescents.[14] Children with greater dietary diversity and vegetable intake may face higher academic pressures and reduced outdoor time, factors not fully captured by available covariates.

While school type was associated with refractive error in unadjusted analyses, this association attenuated after multivariable logistic regression adjustment. This suggests that school type primarily reflects underlying socioeconomic and urban factors, with its apparent effects likely mediated through differences in academic intensity, near-work demands, and parental expectations rather than an independent effect of the school environment itself.

Evidence from large epidemiological studies supports this observation. Zhang *et al.* demonstrated that each additional year of formal schooling was associated with a measurable increase in myopic refractive shift among children and adolescents indicating a dose-response relationship between education and myopia risk.[15] Likewise, the Beijing Childhood Eye Study reported significantly higher myopia prevalence among students enrolled in “key schools,” which represent more academically competitive educational settings, further reinforcing the link between educational intensity and refractive error development.[16]

Studies from low- and middle-income countries support these findings. Research from North India revealed that children attending private schools had significantly higher odds of myopia compared to those in government schools, possibly reflecting differences in academic pressure, screen use, and outdoor activity patterns.[17] Similarly, school-based studies

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from Central Asia have shown that higher grade levels were associated with increased odds of myopia, emphasizing the cumulative effect of educational exposure over time.[18]

The absence of significant associations with screen time in our multivariable logistic regression model contrasts with growing evidence from large quantitative syntheses demonstrating a positive dose-response association between digital screen exposure and myopia risk. A recent systematic review and dose-response meta-analysis of 45 observational studies found that each additional hour of daily screen time was associated with approximately 21 % higher odds of myopia in children and adolescents, with a sigmoidal pattern of risk increasing substantially between 1 and 4 hours of daily exposure, underscoring the importance of capturing continuous exposure and dose effects in analytic models.[19]

Several reasons may explain why our findings differ from earlier studies. Screen time was measured using a simple binary cut-off (≥90 minutes), which may not have been sensitive enough to capture dose–response effects reported in the literature. Additionally, because most participants exceeded this threshold, limited variability may have reduced our ability to detect independent associations in adjusted models. The type and context of screen use may also be more relevant than total screen time alone. The elastic net model identified screen time as a modest contributor to refractive error (OR 1.09 per hour), suggesting that subtle effects may be better detected using continuous measures and penalized modelling techniques. Similarly, sleep duration showed a significant unadjusted association but lost significance after adjustment, indicating that its effects may be mediated through other lifestyle factors. The small protective effect observed in the elastic net model (OR 0.96 per hour) highlights the need for future studies using objective measurements and analytical approaches capable of capturing complex and interacting behavioral exposures. These interpretations are supported by recent meta-analyses demonstrating dose-dependent associations between screen time and myopia, and inverse relationships between sleep duration and myopia risk, particularly in unadjusted or minimally adjusted models.[20]
This study employed robust methodology, including both conventional multivariable regression and elastic net regularized regression, enhancing confidence in the observed patterns. The elastic net approach is particularly valuable when predictors exhibit intercorrelation, as it improves stability and reduces overfitting while performing variable selection. The consistency of findings across both analytical approaches supports the validity of our results. The large sample size, comprehensive assessment of multiple domains, and inclusion of both rural and urban populations enhance generalizability within the North Indian context. By systematically incorporating nutritional, dietary, and health variables alongside demographic and lifestyle factors, we were able to evaluate multiple competing hypotheses regarding refractive error determinants.

VI. CONCLUSION

This study demonstrates that refractive error affects approximately one-quarter of school-going children in Mathura, Uttar Pradesh, with urban residence and increasing age emerging as the predominant independent determinants. The 24.1% prevalence and substantial urban-rural disparity highlight a significant and inequitable burden of paediatric vision impairment. Strengthening school-based vision screening programs, particularly in urban settings and among older children, while developing interventions to promote outdoor activity and regulate near-work demands, offers the most evidence-based approach to addressing this growing public health challenge. Future research should focus on modifiable risk factors and evaluate sustainable strategies for refractive error prevention and management in resource-constrained settings.

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