

Prevalence and Rural-Urban Equity of Vision-Screening Outcomes in Nearly 5,000 Polish Schoolchildren: A Population-Based Cross-Sectional Study

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Abstract

Uncorrected refractive error is a leading cause of avoidable visual impairment in children, and population-based data on screening equity remain scarce outside East Asia, particularly in Central Europe. We analyzed a population-based cross-sectional cohort of 4,902 children examined through a regional school vision-screening program in Poland. Astigmatism was the most prevalent measurement-derived abnormality (35.2%, 95% CI 33.9–36.5%), followed by reduced unaided visual acuity (13.5%) and myopia (12.3%); 32.8% had a recorded referral for further ophthalmic assessment. In an adjusted mixed-effects model accounting for school-level clustering, referral odds increased by 6.7% per year of age (odds ratio 1.067; 95% CI 1.038–1.097), while sex and rural-versus-urban residence showed no independent association. Across eight screening outcomes, adjusted rural-urban prevalence ratios ranged from 0.914 to 1.070, none significant after false-discovery-rate correction. One exception emerged in age-stratified analysis: amblyopia was significantly lower in rural than urban 12-15-year-olds (prevalence ratio 0.523, 95% CI 0.363–0.754; $q = 0.015$), a localized, hypothesis-generating finding. Referral prevalence also varied more than threefold across schools, independent of measured demographic factors, highlighting age and between-school variation, rather than residence, as the principal drivers of referral in this program.

Introduction

Uncorrected refractive error remains the leading cause of avoidable visual impairment in children worldwide, and population-based estimates suggest that tens of millions of children are affected globally, with astigmatism, myopia, and hyperopia accounting for the majority of cases¹.

A 2021 Global Burden of Disease analysis confirmed that refractive disorders remain a substantial and unevenly distributed contributor to years lived with disability across all age groups, including children and adolescents², while pooled population-based data indicate considerable regional heterogeneity in the prevalence and composition of pediatric uncorrected refractive error that is not fully explained by known risk factors³. Because uncorrected refractive error in childhood can affect learning, school performance, and long-term visual development, early identification through vision screening is widely regarded as a public-health priority.

School-based vision screening is the principal strategy for identifying children who require further ophthalmic assessment. Yet, a 2018 Cochrane systematic review found only seven eligible randomized trials worldwide and concluded that the benefits of school screening programs-and the influence of the geographical and socio-economic setting in which they are conducted-remain insufficiently quantified⁴. This evidence gap is particularly acute for large, real-world, population-based screening programs outside East Asia, where most of the existing high-volume pediatric refractive data originate.

In Poland specifically, foundational cycloplegic studies from the 2000s reported a myopia prevalence of approximately 13% and a positive age gradient in a sample of over 4,000 schoolchildren from the

Szczecin region⁵, with an early urban-rural comparison within the same population reporting differences in the distribution of refractive errors between city- and countryside-dwelling children⁶. More recent non-cycloplegic data from 1,041 children across 50 Polish schools reported a considerably lower astigmatism prevalence of 7.3%⁷-markedly discrepant from rates reported in several other European and non-European cohorts, and illustrative of how methodology, age range, and regional sampling can produce widely varying prevalence estimates even within the same country. These differences may reflect variation in study methods, age distribution, and regional sampling, making direct comparison between Polish cohorts difficult. Beyond overall prevalence, whether children's access to timely referral and diagnosis varies by area of residence is a central, unresolved equity question. Evidence from the United States indicates a substantial maldistribution of pediatric eye-care practitioners between urban and rural or underserved regions⁹, and a 2024 National Academies of Sciences, Engineering, and Medicine report identified rural residence as one of several structural barriers to timely identification and treatment of childhood visual disorders¹⁰. Consistent with this, recent large school-based screening cohorts in the United States and historical UK data have linked neighborhood-level deprivation and social vulnerability indices to differences in referral rates and diagnosed ocular conditions^{11,12}. It remains unclear whether similar rural-urban differences occur in Central European school-screening programmes. This question has not previously been examined in this population using analyses that account for multiple testing and school-level clustering.

A directly relevant precedent comes from the same region as the present study: a pilot cohort of 1,049 children aged 7–9 years from the Lubelskie Voivodeship reported myopia, hyperopia, and astigmatism prevalences of 3.7%, 16.9%, and 7.8%, respectively, and additionally found a significantly higher raw (unadjusted) astigmatism prevalence in urban than rural schools⁸. That pilot program, conducted under the same regional public-health initiative that preceded the present screening effort, was informative but limited by its modest sample size and lack of adjustment for age, sex, or school-level clustering, precluding robust conclusions about genuine geographic disparity.

Building on this precedent, we analyzed a substantially larger, population-based cross-sectional cohort of 4,902 children examined through the Lublin Digital Union (LUC) school vision-screening program. Using Wilson score intervals, Benjamini-Hochberg false-discovery-rate correction for multiple comparisons, and modified Poisson regression with school-clustered variance, we aimed to describe the prevalence of recorded and measurement-derived screening outcomes, examine demographic factors associated with referral, and assess rural-urban differences after adjustment for age, sex, and school-level clustering.

Methods

Study design and setting

We conducted a population-based cross-sectional analysis of vision-screening data collected through the LUC school vision-screening programme, a regional public-health initiative in the Lubelskie

Voivodeship, Poland. This programme extends an earlier regional pilot screening effort conducted in the same voivodeship in 2021–2022⁸. The study is reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement for cross-sectional studies¹³.

Data source and processing

Data were extracted from a single-sheet source workbook (5,028 examination rows, 52 columns) containing participant- and site-identifying fields. The source workbook was read without modification; all cleaning, recoding, and derivation steps were performed on in-memory analytical copies, and only aggregate, non-identifying results (summary tables, quality-control counts, and figures) were exported. No row-level data, names, identifiers, addresses, or contact details are reported in this manuscript.

Cohort construction

Examination records were retained if they had a valid examination date and complete core binary outcome fields (schema-valid rows). For participants with more than one valid examination, the most recent record was retained (ties on the same date resolved by the later source row), yielding a single record per participant (Fig. 1). Age-dependent analyses were further restricted to participants with a calculated age within a pre-specified plausible range of 4–20 years; records with an unparseable birth date or an implausible age were excluded only from age-dependent analyses. The fully adjusted referral model additionally required complete data on age, sex, area of residence, school identifier, and referral status.

Operational definitions

Sex and area of residence (urban/rural, assigned by school location) were standardized from source fields; unrecognized values were retained and reported as “unknown” rather than excluded. Grade and age were derived from examination and birth dates. Decimal unaided visual acuity (VA) values of exactly zero were treated as an ambiguous non-measurement sentinel and set to missing for all VA- and logMAR-based analyses; valid decimal VA values were converted to logMAR. Reduced unaided VA was defined as decimal VA < 0.8 in either eye. Spherical equivalent (SE) was calculated as sphere + ½ cylinder; myopia was defined as SE ≤ -0.5 D, high myopia as SE ≤ -6 D, and hyperopia as SE ≥ + 2.0 D in either eye, following International Myopia Institute (IMI) consensus thresholds¹⁴. Astigmatism was defined as an absolute cylinder ≥ 0.75 D in either eye. Sphere and cylinder values outside a pre-specified physiologically plausible range (sphere – 15.0 to + 15.0 D; cylinder – 10.0 to + 10.0 D) were set to missing for the affected measurement. Referral, amblyopia, squint, and “bad eyesight” status were taken directly from source database flags and are distinguished throughout from the measurement-derived definitions above, as these two categories of outcome are not interchangeable (Results). Database diagnostic-field

classifications of myopia, hyperopia (“foresight”), and astigmatism were derived from free-text eye-diagnosis fields and reported separately for comparison.

Statistical analysis

Prevalence estimates and their 95% confidence intervals were calculated using the Wilson score method¹⁵. Unadjusted rural-versus-urban comparisons used the Newcombe-Wilson method for the difference in two independent proportions¹⁶, alongside crude prevalence ratios and odds ratios. Adjusted rural-versus-urban prevalence ratios were estimated using modified Poisson regression with a robust (“sandwich”) variance estimator clustered by school (the cluster unit), adjusting for age and sex¹⁷. An exploratory mixed-effects logistic regression model of recorded referral included age (centered, per 1-year increase), sex, and area as fixed effects, with a school-level random intercept. Because rural-urban comparisons were performed across eight outcomes (and, in stratified analyses, across three age bands within each outcome), we controlled the false discovery rate using the Benjamini-Hochberg procedure within each outcome family and report FDR-adjusted q-values alongside nominal P-values¹⁸. Age strata for stratified analyses (4–7, 8–11, and 12–15 years) were pre-specified and restricted to strata containing at least 30 participants in both areas. All analyses were performed in MATLAB (version 25.1.0, R2025a Update 1, MathWorks).

Results

Study cohort and data quality

Of 5,028 imported examination records, 4,907 (97.6%) passed schema validation, and after retaining the most recent valid examination per child, 4,902 participants formed the primary analytic cohort (Fig. 1; Supplementary Table S1 for the full data-quality audit). The cohort was balanced by sex (2,451 boys, 50.0%; 2,430 girls, 49.6%; 21 unknown, 0.4%) and comprised 3,514 children (71.7%) from rural schools and 1,383 (28.2%) from urban schools (5 unknown, 0.1%), distributed across grades 1–8 (Table 1). Median age was 10.3 years (IQR 8.5–12.4); age-dependent analyses were restricted to the pre-specified plausible range of 4–20 years, which excluded 48 records with an unparseable birth date and 276 records with an implausible calculated age (Fig. 1). Only 18.7% of children had a previous eye examination on record and 12.2% had a recorded corrected visual acuity, reflecting the screening (rather than diagnostic) nature of the programme. After further restricting to complete data on age, sex, area, school, and referral status, 4,554 children (92.9% of the primary cohort) from 60 schools were available for the adjusted referral model.

Table 1
Baseline characteristics of the participant-level cohort (N = 4,902)

Characteristic	n	% (or Mean $\pm$ SD / Median [IQR])
Sex - Female	2,430	49.6%
Sex - Male	2,451	50.0%
Sex - Unknown	21	0.4%
Area - Rural	3,514	71.7%
Area - Urban	1,383	28.2%
Area - Unknown	5	0.1%
Grade 1	737	15.0%
Grade 2	760	15.5%
Grade 3	708	14.4%
Grade 4	623	12.7%
Grade 5	621	12.7%
Grade 6	560	11.4%
Grade 7	470	9.6%
Grade 8	415	8.5%
Grade - Unknown	8	0.2%
Age, years	4,855	median 10.3 [IQR 8.5–12.4]
Previous eye examination on record	918	18.7%
Corrected VA recorded	599	12.2%
Unaided VA, right eye, decimal	4,894	median 1.0 [IQR 1.0–1.0]; mean 0.92 ± 0.21
Unaided VA, left eye, decimal	4,891	median 1.0 [IQR 1.0–1.0]; mean 0.92 ± 0.22
Spherical equivalent, right eye, D	4,900	median 0.13 [IQR 0.00–0.38]; mean 0.09 ± 0.91
Spherical equivalent, left eye, D	4,902	median 0.13 [IQR – 0.13–0.38]; mean 0.06 ± 0.86
<i>Raw calculated age contained a small number of physiologically implausible values (e.g., due to unparseable birth dates), which were excluded from age-dependent analyses per the pre-specified 4-20-year plausibility range (Methods; Fig. 1); the values shown here (median, IQR) are robust to these outliers. Percentages are of the full participant-level cohort (N = 4,902) unless otherwise noted; denominators for continuous measures reflect available (non-missing) observations.</i>		

Prevalence of vision-screening outcomes

Astigmatism (either eye, cylinder ≥ 0.75 D) was the most prevalent measurement-derived abnormality, affecting 35.2% of children (1,725/4,901; 95% CI 33.9–36.5%), followed by reduced unaided visual acuity (13.5%, 661/4,890; 95% CI 12.6–14.5%) and myopia (either eye, SE ≤ -0.5 D; 12.3%, 603/4,900; 95% CI 11.4–13.3%; Fig. 2). Hyperopia (SE $\geq +2.0$ D) was less common (1.9%, 93/4,900), as was high myopia (SE ≤ -6 D; 0.2%, 8/4,900). A recorded referral was present in 32.8% of participants (1,608/4,902; 95% CI, 31.5–34.1%), whereas recorded amblyopia and squint were substantially rarer (5.0% and 0.6%, respectively). Database diagnostic-field classifications yielded consistently lower prevalences than the corresponding measurement-derived definitions (myopia 7.6% vs 12.3%; astigmatism 8.7% vs 35.2%), indicating that coded diagnoses in the source system under-capture measurement-defined refractive abnormality and should not be used interchangeably with threshold-based definitions.

Unadjusted referral prevalence varied modestly across demographic subgroups (Supplementary Fig. S1), rising from 29.7% in children aged 4–7 years to 37.5% in those aged 12–15 years, and was slightly higher among girls than boys (34.2% vs 31.5%). Between-school referral prevalence, among the 61 schools with at least 20 examined children, ranged more than three-fold, from 16.7% (School 53, $n = 48$) to 50.0% (School 16, $n = 62$). Confidence intervals were wider in smaller schools (Supplementary Fig. S2). School-level clustering was therefore accounted for in the adjusted analysis.

Determinants of referral: an adjusted multilevel model

In an exploratory mixed-effects logistic-regression model of recorded referral (4,554 complete cases, 60 schools, school-level random intercept), each additional year of age was associated with a 6.7% increase in the odds of referral (adjusted OR 1.067, 95% CI 1.038–1.097, $P < 0.001$; Fig. 3). Boys had somewhat lower odds of referral than girls, an association that narrowly did not reach conventional significance (adjusted OR 0.885, 95% CI 0.781–1.002, $P = 0.053$). Rural residence was not independently associated with referral after adjusting for age and sex (adjusted OR 0.997, 95% CI 0.851–1.166, $P = 0.966$), with a confidence interval symmetric around the null.

Rural-urban equity after adjustment for age and sex

Across all eight screening outcomes, crude rural-urban prevalence differences were modest (Supplementary Fig. S3), and none of the age- and sex-adjusted, school-clustered prevalence ratios reached statistical significance after Benjamini-Hochberg correction for multiplicity (Fig. 4; lowest FDR $q = 0.295$, for both squint and astigmatism). Adjusted prevalence ratios (rural vs urban) were close to unity for referral (PR 0.995, 95% CI 0.919–1.078, $q = 0.902$), reduced unaided visual acuity (PR 1.036, 95% CI 0.858–1.251, $q = 0.887$), myopia (PR 0.944, 95% CI 0.844–1.055, $q = 0.828$), hyperopia (PR 1.070, 95% CI 0.673–1.702, $q = 0.887$) and astigmatism (PR 0.914, 95% CI 0.835–1.000, $q = 0.295$). Amblyopia showed the largest point-estimate difference (PR 0.639, 95% CI 0.212–1.924, $q = 0.851$). However, the confidence interval was wide due to the low number of events, so that no clear conclusion could be drawn. Across

nearly all eight adjusted condition-specific models, age remained a consistent, statistically significant predictor ($P < 0.001$ for referral, reduced unaided VA, amblyopia, the recorded bad-eyesight flag, myopia, and astigmatism). At the same time, sex was significantly associated with reduced unaided VA, amblyopia, and the bad-eyesight flag, with boys consistently at lower adjusted risk (Supplementary Table S2).

Age-specific analysis of rural-urban differences in amblyopia

Because an overall null association can mask effects that are confined to specific age groups, we additionally examined rural-urban contrasts within three age strata (4–7, 8–11 and 12–15 years; each stratum containing ≥ 30 children per area; Supplementary Fig. S4). Of 24 age-by-condition comparisons, only one remained significant after FDR correction: amblyopia prevalence among 12-15-year-olds was lower in rural than urban children (6.1% vs 11.6%; prevalence ratio 0.523, 95% CI 0.363–0.754; absolute difference – 5.54 percentage points, 95% CI -9.38 to -2.27; $q = 0.015$; Fig. 5). All other age-stratified adjusted comparisons had $q \geq 0.060$ (Supplementary Fig. S5), and the heatmap of joint age-by-area prevalence (Supplementary Fig. S6) confirmed that referral, reduced unaided visual acuity, myopia and astigmatism all peaked in the oldest stratum (12–15 years) in both urban and rural settings, consistent with the overall age gradient identified in the adjusted referral model.

Discussion

In this population-based analysis of 4,902 schoolchildren screened through the LUC programme, astigmatism was the most common measurement-derived abnormality (35.2%), affecting roughly one in three children. In contrast, 32.8% of the cohort received a recorded referral for further ophthalmic assessment. Age was the only demographic factor consistently and robustly associated with referral and with most individual conditions across all adjusted models we fitted. In contrast, rural residence showed no independent association with any of the eight screening outcomes after accounting for age and sex. A single, localized exception emerged only within a pre-specified age-stratified analysis: amblyopia was significantly less prevalent among rural than urban 12-15-year-olds. These results provide updated data on screening outcomes and rural-urban differences in this region, based on analyses that accounted for age, sex, and school-level clustering.

The astigmatism prevalence observed here (35.2%) is markedly higher than the 7.3% recently reported in a smaller, non-cycloplegic sample of 1,041 Polish schoolchildren using an ostensibly similar ≥ 0.75 D threshold⁷. Also, it exceeds the myopia and hyperopia prevalences reported in earlier Polish cohorts from the 2000s^{5,6}. Several factors may explain this difference, including differences in age distribution, near-work exposure, autorefraction protocols, cycloplegic status, and genuine secular trends in refractive error, consistent with global trends reported over the past two decades^{2,3}. We are unable to arbitrate between these explanations with cross-sectional data from a single programme. The approximately

fivefold difference also indicates that prevalence estimates from different Polish screening studies should be compared with caution. We also found that source database diagnostic codes substantially under-captured measurement-derived abnormality (e.g., 8.7% coded astigmatism versus 35.2% measurement-derived), a discrepancy with direct relevance for health administrators who may rely on coded registry data to estimate pediatric eye-care burden; our results suggest that such estimates could be severalfold too low.

The consistent, approximately 6–7%-per-year increase in referral odds, together with parallel age gradients for reduced unaided visual acuity, myopia, and astigmatism, is consistent with the well-documented tendency of school-age refractive error-particularly myopia and astigmatic shift-to increase with cumulative near-work and school exposure^{2,3}. This pattern reinforces the rationale for repeated, longitudinal screening across the school years rather than a single early check, and is consistent with international calls for sustained rather than one-off screening coverage⁴.

Our principal a priori motivation was to test, with adequate statistical power and appropriate correction for multiple comparisons and school-level clustering, whether the raw urban-rural astigmatism gap previously reported in a smaller regional pilot from the same voivodeship⁸ reflected a genuine disparity. In our substantially larger and adjusted analysis, the corresponding prevalence ratio for astigmatism (0.914, rural versus urban) remained directionally similar to the pilot's finding. Still, it did not survive FDR correction ($q = 0.295$), and none of the eight adjusted rural-urban comparisons reached significance. This pattern is compatible with two, not mutually exclusive, interpretations: first, that the pilot's smaller, unadjusted sample was more susceptible to chance imbalance or residual confounding by age and school composition; and second, that genuine rural-urban differences in this setting, if they exist, are considerably smaller in magnitude than has been reported in some other health systems. Notably, our finding of broad geographic equity contrasts with evidence from the United States, where rural and underserved areas show marked shortages of paediatric eye-care practitioners and correspondingly worse access^{9,10,11}. Differences in healthcare and school-screening systems may partly explain this contrast. In Poland, the school-based screening model, delivered through the compulsory education system and supported by universal public healthcare coverage, may provide more uniform access to rural and urban children than systems that rely on discretionary access or the local availability of practitioners. This interpretation is consistent with historical UK evidence that vision-screening outcomes track measures of area-level deprivation more closely than urban-rural status per se¹²-a distinction our dataset, which lacked a deprivation index, could not directly test and which represents an important direction for future work.

The one comparison that did survive multiplicity correction-lower amblyopia prevalence among rural than urban 12-15-year-olds-warrants cautious interpretation. Amblyopia is, by definition, a developmental condition with a treatment window concentrated in early-to-middle childhood; its continued presence at ages 12–15 in either setting most plausibly reflects children who were not identified or successfully treated earlier, rather than new-onset disease. Higher recorded amblyopia prevalence in urban children

may reflect differences in diagnostic ascertainment rather than a true difference in disease prevalence. For example, urban children may have had greater access to previous ophthalmic or orthoptic assessment. Distinguishing genuine prevalence differences from differential detection was not possible within a single cross-sectional screening pass, and we present this finding as hypothesis-generating rather than conclusive. This finding should be examined in a longitudinal study.

Referral prevalence varied more than threefold across schools with adequate sample size (16.7–50.0%), and this variation was not explained by the age-, sex-, and area-adjusted model. While some of this heterogeneity is expected from sampling variation, particularly in smaller schools, its magnitude suggests that school-level or examiner-level factors—such as local screening protocol adherence, examiner training, or referral thresholds—may meaningfully influence outcomes independently of the child-level factors modelled here. We did not have access to school-level covariates, such as school size, examiner identity, or urbanicity beyond the binary area classification, that would allow us to explain this heterogeneity. Further analyses of school-level factors will require additional information on school characteristics and examiner-related variables.

This study's principal strengths are its population-based scale (nearly 5,000 children, more than four times the size of the only directly comparable prior regional cohort⁸), its use of Wilson score intervals, Benjamini-Hochberg correction across outcome families, and clustering-aware modified Poisson regression methods that substantially reduce the risk of false-positive geographic contrasts relative to unadjusted comparisons. Several limitations should nonetheless be considered. First, the design is cross-sectional; observed associations, including the age gradient and the age-specific amblyopia contrast, cannot establish causality or temporal sequence. Second, referral, amblyopia, squint, and “bad eyesight” are recorded source flags whose ascertainment may vary by examiner or site and are not interchangeable with our measurement-derived definitions, as the substantial gap between coded and measured prevalence illustrates. Third, best-corrected visual acuity, recent examination history, and spectacle-wear data were available for only a minority of participants, and available-case denominators were used throughout; residual bias from non-random missingness cannot be excluded. Fourth, the dataset lacked a reliable field for excluding children with pre-existing non-refractive ocular pathology, and the cylinder axis was recorded as zero in nearly all rows, rendering it unusable for analysis. Fifth, our data derive from a single Polish voivodeship, and generalisability to other regions or healthcare systems, particularly those with different models of school-health service delivery, should not be assumed. Finally, we deliberately excluded from this analysis a set of exploratory predictive models for referral risk that we identified as being affected by deterministic target leakage (worse-eye visual acuity and spherical equivalent were supplied as predictors of an outcome partly defined by those same measurements); we plan to report a corrected, leakage-free version of this predictive analysis separately.

In this population-based cohort of 4,902 schoolchildren from the Lubelskie Voivodeship, we found a high burden of measurement-derived astigmatism. We reduced visual acuity, a robust and consistent age gradient in referral risk, and, contrary to some international evidence and to an earlier, smaller regional pilot, no overall rural-urban disparity in vision-screening outcomes once age, sex, and school clustering

were accounted for. Within this screening program, we found no overall evidence of rural-urban differences in referral after adjustment for age, sex, and school-level clustering. The lower recorded prevalence of amblyopia among rural children aged 12–15 years and the marked variation in referral rates between schools require further investigation.

Ethics statement

This study was approved by the Bioethics Committee at the Medical University of Lublin, under resolution no. KE-0254/96/03/2023, with subsequent amendments to the study protocol, participant information sheets, informed consent forms, personal-data-processing consent forms, and image-use consent form approved under resolution no. KB-0024/80/05/2025, dated 22 May 2025. The Committee operates in accordance with the principles of Good Clinical Practice (GCP). The study was conducted in accordance with the Declaration of Helsinki and applicable Polish regulations governing biomedical research (the Act of 5 December 1996 on the Profession of Physician and Dentist and the Regulation of the Minister of Health of 26 January 2023 on Bioethics Committees). Written informed consent for participation and for processing of personal data was obtained from the parents or legal guardians of all participating children, using the consent forms and participant information materials approved by the Bioethics Committee.

Declarations

Code availability

The MATLAB analysis code (luceye_medical_edu.m, luceye_manuscript_analysis.m) used to generate the aggregate results and figures reported here is available from the corresponding author upon reasonable request.

Competing interests

The authors declare no competing interests.

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Author Contribution

J.D.-S. and A.B. contributed equally to this work. J.D.-S. conceived and designed the study, supervised clinical data collection, and provided ophthalmological interpretation of the findings. A.B. contributed to clinical data acquisition, data curation, and critically revised the manuscript. K.L. contributed to clinical data acquisition and screening coordination. M.W. and K.J. designed the statistical and computational analysis pipeline, performed the statistical analyses, and produced the figures, tables, and Source Data files. R.R. supervised the project and critically revised the manuscript for clinical content. All authors contributed to drafting and critically revising the manuscript and approved the final version for submission.

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Data Availability

The datasets generated and/or analysed during the current study are not publicly available due to data protection and school safeguarding considerations, as the underlying dataset contains participant- and school-identifying fields. The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to institutional data-protection approval and, where applicable, a formal data-sharing agreement.

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Figures

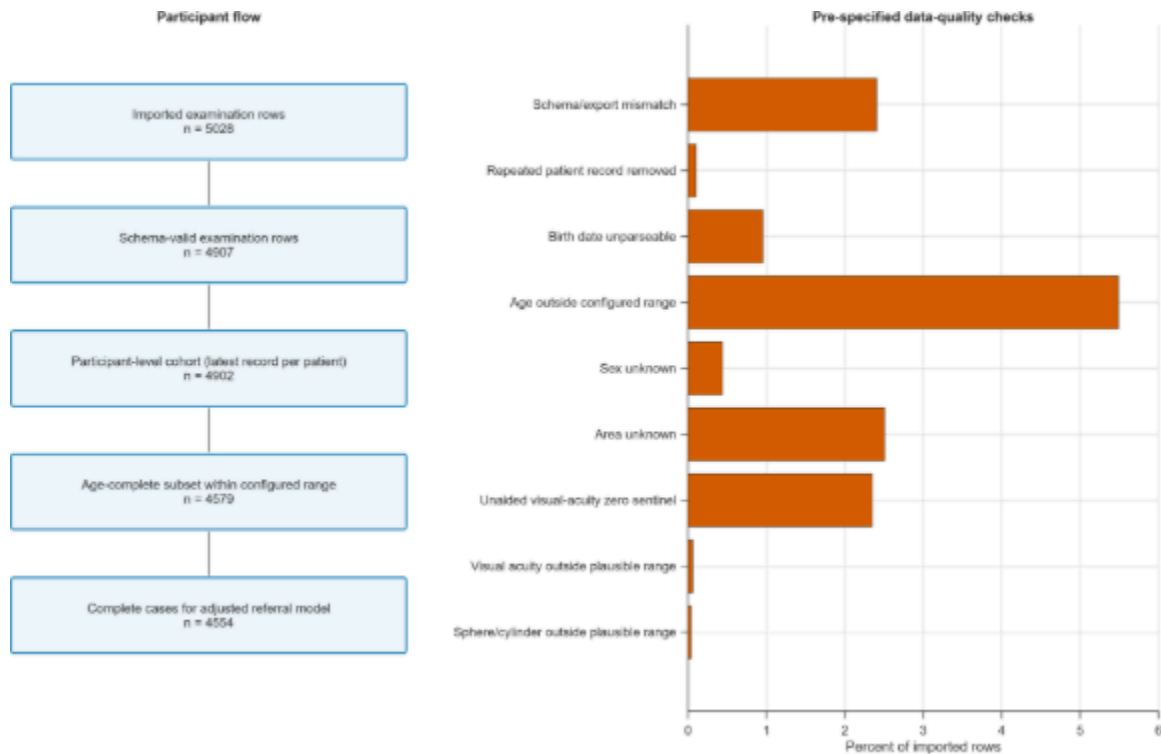


Figure 1

Participant flow and data-quality assessment. (a) Participant flow from 5,028 imported examination rows to 4,907 schema-valid rows, 4,902 unique participants after retaining the latest valid examination per patient, 4,579 participants with a plausible age (4-20 years), and 4,554 complete cases used in the adjusted referral model (Fig. 3). (b) The first nine pre-specified data-quality checks, expressed as a percentage of all imported rows. The largest exclusions were age outside the configured range (5.5%), unknown area of residence (2.5%), schema/export mismatch (2.4%), and the unaided-visual-acuity zero sentinel (2.3%); duplicate records and physiologically implausible measurements were uncommon.

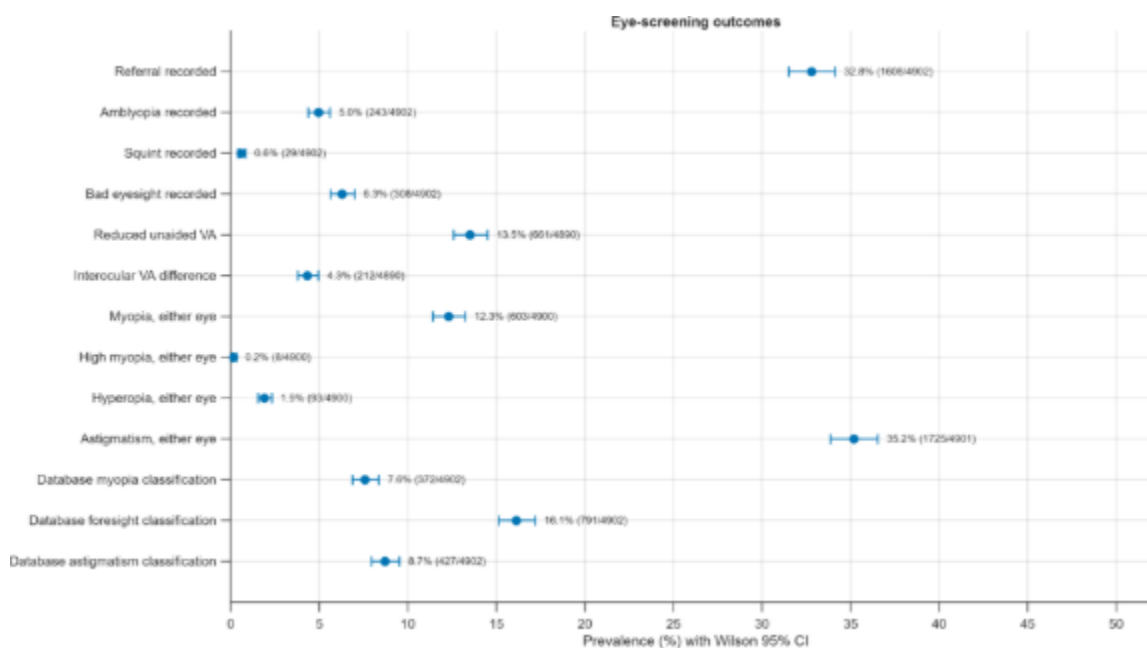


Figure 2

Prevalence of recorded and measurement-derived vision-screening outcomes (N = 4,902). Points show prevalence, and whiskers show Wilson 95% confidence intervals; labels give the percentage and event count over the available denominator, which varies slightly across outcomes that require complete bilateral visual-acuity, refraction, or cylinder data. Astigmatism was the most prevalent outcome (35.2%; 1,725/4,901), followed by referral (32.8%; 1,608/4,902), reduced unaided visual acuity (13.5%; 661/4,890), and myopia (12.3%; 603/4,900). Database diagnostic-field classifications of myopia, hyperopia, and astigmatism are shown alongside their corresponding measurement-derived definitions for comparison.

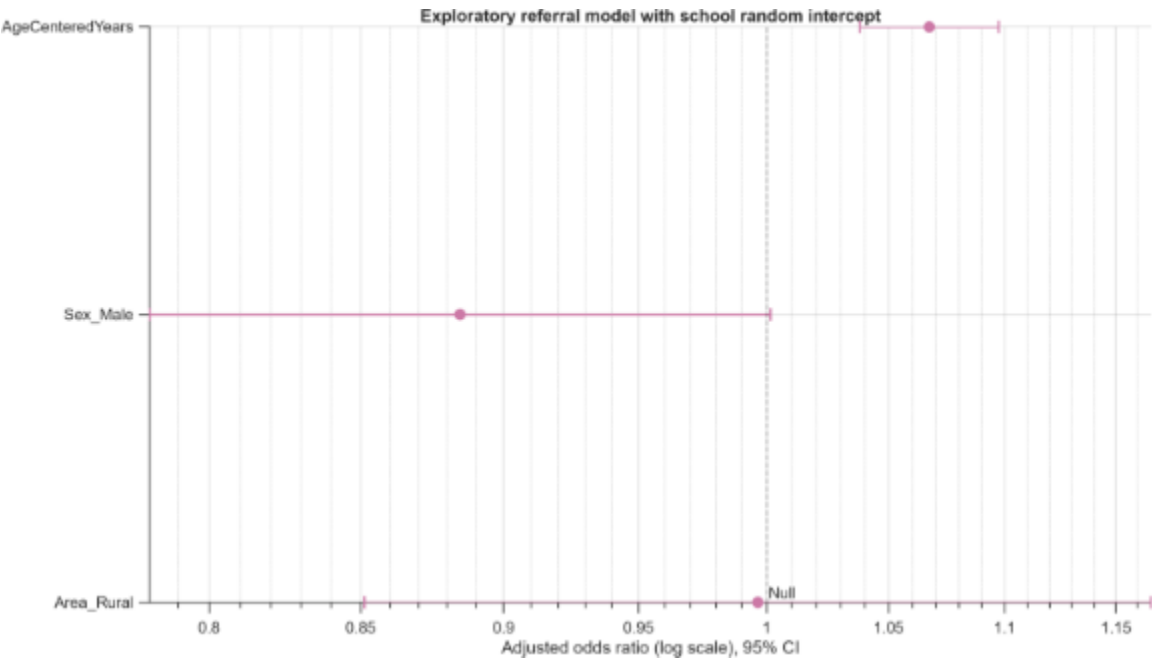


Figure 3

Adjusted multilevel model of recorded referral. An exploratory mixed-effects logistic regression model for recorded referral, including 4,554 complete cases from 60 schools. Age (per 1-year increase, centered), sex, and rural versus urban area were modeled as fixed effects, with a school-level random intercept. Points show adjusted odds ratios on a logarithmic scale; whiskers show 95% confidence intervals; the dashed line marks the null value (OR = 1.00). Reference categories were female sex and urban area. Referral odds increased by 6.7% per year of age (OR 1.067, 95% CI 1.038-1.097, $P < 0.001$); estimates for sex (OR 0.885, 95% CI 0.781-1.002, $P = 0.053$) and area (OR 0.997, 95% CI 0.851-1.166, $P = 0.966$) included the null.

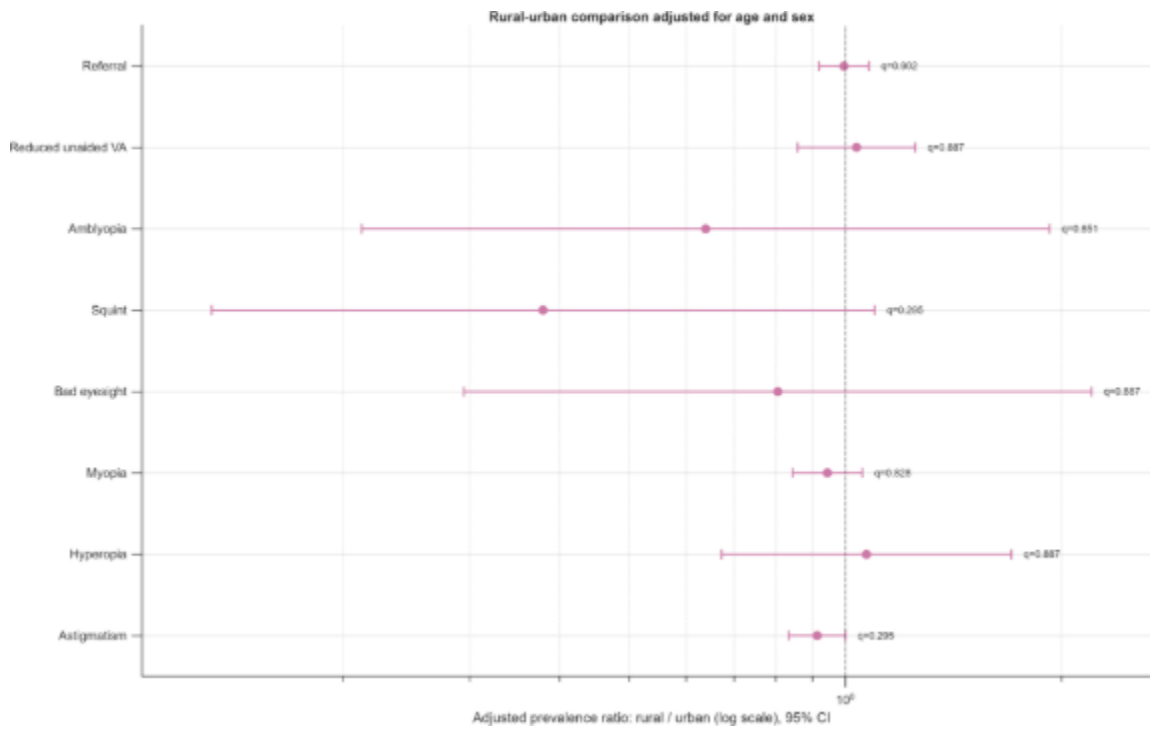


Figure 4

Age- and sex-adjusted rural-urban prevalence ratios across eight screening outcomes. Prevalence ratios (rural relative to urban) estimated by modified Poisson regression, adjusted for age and sex, with robust variance clustered by school. Points show adjusted prevalence ratios on a logarithmic scale; whiskers show 95% confidence intervals; the dashed line marks the null ratio (PR = 1.00). q-values are computed using the Benjamini-Hochberg false-discovery-rate procedure across the eight outcomes. No comparison reached $q < 0.05$ (lowest $q = 0.295$, for squint and astigmatism); adjusted PRs ranged from 0.914 (astigmatism) to 1.070 (hyperopia).

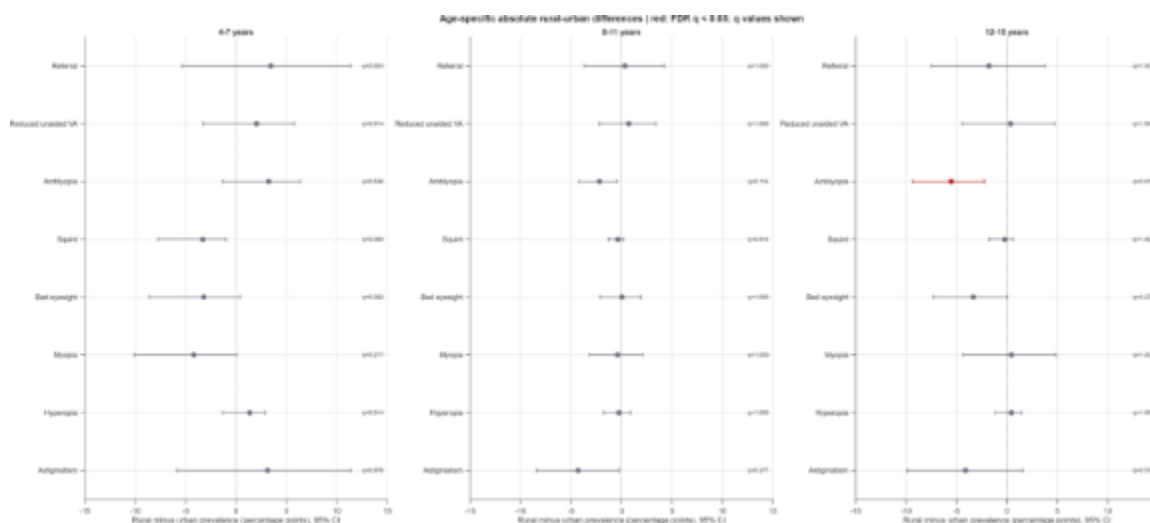


Figure 5

Age-specific absolute rural-urban differences in screening-outcome prevalence. Differences are expressed as rural-minus-urban percentage points within three pre-specified age strata (4-7, 8-11, and 12-15 years; each stratum containing ≥ 30 participants per area). Points show differences; whiskers show 95% confidence intervals; the dashed line marks no difference. Red indicates Benjamini-Hochberg-adjusted $q < 0.05$ across the full set of 24 age-by-condition comparisons. The only significant difference was amblyopia among 12-15-year-olds, 5.54 percentage points lower in rural than urban children (95% CI -9.38 to -2.27; $q = 0.015$); all other intervals crossed zero after correction for multiplicity.

Supplementary Files

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