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· Investigation ·

Centile curves of refraction in children and adolescents aged 5–18 in Hubei Province: a study based on GAMLSS to predict refraction development

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Abstract
● **AIM:** To establish percentile curves of refractive development for children and adolescents aged 5–18y in Hubei Province.
● **METHODS:** A cross-sectional study was conducted in 103 county-level administrative districts of Hubei Province *via* a multistage stratified cluster sampling strategy. Participants underwent non-cycloplegic autorefraction, and spherical equivalent refraction (SER) of the right eye was calculated. Generalized additive models for location, scale, and shape (GAMLSS) were applied to construct age-specific standard SER percentile curves stratified by gender and region. Moreover, age-related curves of annual refractive progression rate at each percentile were plotted.
● **RESULTS:** A total of 1 255 454 participants (673 341 boys and 582 113 girls) aged 5–18y (mean age: 11.13±3.59y) were enrolled. An overall myopic shift trend was observed with advancing age. The median SER was +0.25 diopters (D) at 5 years of age and decreased to -0.50 D at 9 years of age. From 5 to 18 years of age, the refractive progression was -6.63 D at the 3rd percentile, while the values were -3.25 D and -1.00 D at the 50th and 97th percentiles, respectively. Girls and rural children presented higher myopic degrees. The annual age-dependent refractive progression rate curve showed a U-shaped pattern, with greater annual refractive changes in lower percentiles and peak refractive progression occurring at younger ages.
● **CONCLUSION:** Children in lower SER percentiles suffer from more severe myopia and faster refractive progression. Therefore, earlier and targeted intensive myopia interventions are warranted for children with SER below the 50th percentile.
● **KEYWORDS:** percentile curves; spherical equivalent refraction; myopia; children
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INTRODUCTION
Uncorrected refractive error is the leading cause of vision impairment and the second most common cause of blindness worldwide[1]. Over recent decades, both the prevalence and incidence of myopia have increased rapidly worldwide, attracting substantial international attention[2]. Substantial variation exists in myopia prevalence across countries[3]. Epidemiological studies indicate that myopia prevalence is highest in East Asia, followed by Europe and Africa, with urban populations and females exhibiting a higher prevalence under global trends[4]. Refractive development changes with age, typically beginning with moderate hyperopia at birth and gradually shifting toward myopia over time[5]. Refractive reference values are therefore age-specific. Percentile curves are widely used in pediatrics

to assess age-related distributions of variables relative to reference populations, particularly in evaluating child growth and development. Early research on refractive development percentiles was conducted by Chen *et al*[6], who established refractive error percentile curves for Chinese children aged 5–15y to predict the risk of high myopia. Refractive percentile curves are population-specific, and subsequent studies in countries such as Germany, Republic of Korea, Portugal, and Spain have established similar curves for children and adolescents[7-11].

Previous studies on refractive percentiles in Chinese children were primarily conducted under cycloplegic conditions or restricted to non-myopic populations[12]. Although cycloplegic refraction is considered the gold standard for diagnosing refractive errors, non-cycloplegic refraction is frequently used in large-scale vision screening programs. Percentile reference values derived from cycloplegic measurements cannot be directly applied to mass screening settings, as strict adherence may increase the proportion of individuals classified as abnormal and thus the burden on healthcare systems[13-14]. In contrast, refractive percentile studies in European countries have largely relied on non-cycloplegic measurements, precluding direct comparisons between the two nations[15]. Therefore, the development of percentile curves based on non-cycloplegic measurements is both necessary and clinically relevant.

This study fills a critical gap in refractive percentile data for large-scale populations in central China and provides a practical tool for routine vision screening, enabling early identification of children at risk of refractive abnormalities. By analyzing refractive percentile curves across multiple dimensions, including age, sex, and urban–rural residence, this study aims to characterize refractive development in children and explore factors influencing refractive development in Chinese populations. The findings are expected to provide a scientific basis for public health policy formulation. In addition, this study overcomes the limitation of insufficient sample sizes in specific age groups reported in previous studies.

PARTICIPANTS AND METHODS

Ethical Approval The study protocol was approved by the Ethics Committee of Renmin Hospital of Wuhan University (Ethics No.WDRY2020-K211) and was conducted in accordance with the Declaration of Helsinki. Prior to the study, researchers provided standardized education on the study protocol to students *via* their schools, explaining the study objectives, procedures, and safety considerations to students, their parents, and school authorities. Informed consent was obtained from all participating students and their guardians prior to participation.

Study Design This study was a cross-sectional survey conducted in Hubei Province. Hubei Province is located in central China (latitude 29°01′53″–33°06′47″N, longitude 108°21′42″–116°07′50″E) and had a permanent population of 58.3 million at the end of 2021. The survey was conducted annually between September and November, with three rounds of screening completed to date in 2021, 2022, and 2023. Each county-level administrative region served as a survey site, yielding a total of 103 sites. The sample size for each survey site was determined based on the standard sample size calculation formula: $N=\mu^2\times p(1-p)/d^2$. In this formula, N represents the sample size, p the estimated prevalence, and d the permissible error (set at $0.04p$). With a 95% confidence level ($\alpha=0.05$), μ was 1.96. According to data from the National Health Commission, the prevalence of myopia among children and adolescents in mainland China is approximately 52.7% (p). Accordingly, the calculated minimum sample size for each site was approximately 2154 participants. Considering potential absences and non-response, each survey site was required to include more than 2200 students aged 5–18y. All survey sites successfully enrolled participants and met the minimum sample size requirement. A multistage stratified cluster sampling strategy was used in this study (Figure 1).

Inclusion and Exclusion Inclusion: Students aged 5–18y; Students who understand and are willing to participate in eye examinations; Permanent residents of the survey area. Exclusion: Inability to cooperate with the eye examination; Presence of organic ocular pathology, including glaucoma, corneal disorders, refractive media opacities, fundus lesions, strabismus, or a history of ocular surgery; Significant refractive interstitial abnormalities.

Data Collection All participants underwent refractive examinations performed by uniformly trained optometrists or ophthalmologists. Autorefraction was measured using a table-mounted autorefractor (RM-800; Topcon, Tokyo, Japan). Each eye was measured three times, and the mean value was automatically calculated by the device. If the spherical or cylindrical power differed by ≥0.50 diopters (D) between any two of the three measurements for a given eye, additional measurements were obtained until stable readings were achieved. In cases of marked variability among the three measurements for a single eye, participants were asked to rest for 30min before repeat measurements.

Refractive error was expressed as spherical equivalent refraction (SER), which was calculated as the spherical power plus half of the cylindrical power, with cylindrical power expressed in negative cylindrical diopters (CD). In this study, analyses were based on the SER of the right eye.

Statistical Analysis To model the age-specific distribution of SER, we applied generalized additive models for location,

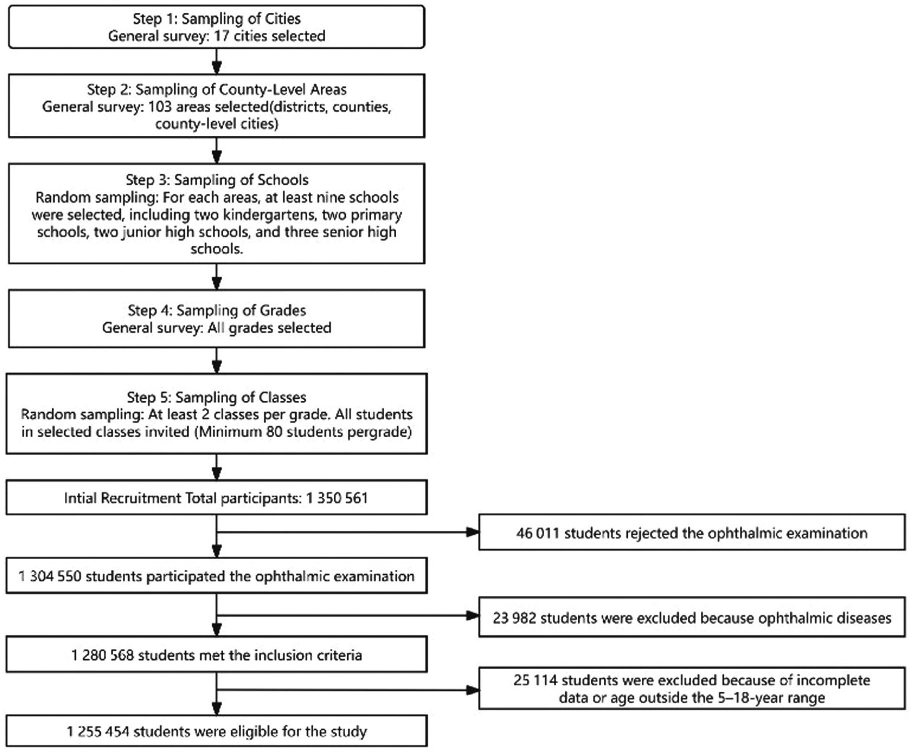

Figure 1 Flowchart of the multi-stage stratified sampling and participant selection process.

scale, and shape (GAMLSS) using R version 4.4.2. This approach allows simultaneous modeling of the mean (μ), variability (σ), and tail behavior (v) as smooth functions of age. SER data were skewed with a heavy lower tail, representing the risk of myopia. Traditional regression or mixed-effects models assume normality and only capture the mean, failing to characterize extreme values and age-related risk structures. GAMLSS provides flexible parametric distributions (*e.g.*, the t-family distribution) and smoothing techniques (*P*-splines), enabling accurate estimation of centile curves and prediction of myopia probability[16]. Factors including age and sex were incorporated into the model fitting. The annual refractive progression rate was defined as the difference in SER between consecutive ages. Curves of age-specific refractive progression rates were plotted for different percentiles. A two-sample *t*-test was used to compare SER between sexes or regions across different age groups.

RESULTS

Age-Specific Percentile Distribution of Refraction in Children and Adolescents A total of 1 255 454 individuals aged 5–18y were included, with a mean age of 11.13±3.59y and a mean SER of -1.53±2.22 D. As shown in Table 1, the 50th percentile SER was +0.25 D at age 5 and shifted to -0.50 D by age 9. With increasing age, SER values across all percentiles demonstrated a progressive myopic shift. From ages 5 to 18, cumulative refractive progression at the 3rd percentile was -6.63 D, compared with -3.25 and -1.00 D at the 50th and 97th percentiles, respectively. Myopia progression was more pronounced at lower percentiles.

Refraction Cut-off Values in Children and Adolescents by Sex or Region Percentile reference intervals for SER were established by sex and region using the GAMLSS model. The study included 673 341 boys and 582 113 girls. As shown in Table 2, the 50th percentile SER was -0.88 D for boys and -1.00 D for girls, with girls exhibiting a significantly higher degree of myopia than boys (t=32.06, P<0.001). From ages 5 to 18, the 3rd percentile shifted by -6.62 D for boys and -6.50 D for girls, while the 50th percentile shifted by -3.13 and -3.38 D, and the 97th percentile by -1.00 and -1.13 D for boys and girls, respectively. Greater refractive changes were observed at lower percentiles than at higher percentiles. The age-specific percentile distributions of SER for boys and girls are shown in Figure 2.

The study included 554 254 urban students and 701 200 rural students. As shown in Table 3, the 50th percentile SER was -0.91 D for urban students and -0.98 D for rural students, with rural students exhibiting significantly lower SER than urban students (t=11.96, P<0.01). At age 5, both the 3rd and 50th percentile SER values were lower in rural students than in urban students, indicating a higher degree of myopia among rural students. With increasing age, differences between urban and rural percentile curves gradually diminished.

Annual Refractive Change Across Ages and Percentiles Figure 3 shows that the annual rate of refractive change follows a U-shaped pattern with age. Before age 9, the annual refractive change increases with age, remains relatively high

Table 1 Age-specific percentile distribution of refraction (D) in children and adolescents

Age (y)	*n*[a]	97th	90th	75th	50th	25th	10th	3rd
5	60076	1.25	0.88	0.63	0.25	-0.25	-0.75	-1.50
6	89906	1.25	0.75	0.50	0.13	-0.25	-0.88	-1.88
7	102526	1.13	0.75	0.38	0.00	-0.50	-1.25	-2.38
8	103315	1.00	0.50	0.25	-0.25	-0.88	-1.75	-3.12
9	106657	0.88	0.50	0.00	-0.50	-1.38	-2.50	-3.88
10	106158	0.75	0.25	-0.13	-0.75	-1.88	-3.13	-4.50
11	103650	0.75	0.25	-0.25	-1.13	-2.38	-3.75	-5.25
12	103053	0.62	0.13	-0.50	-1.50	-2.88	-4.25	-5.88
13	101145	0.50	0.00	-0.75	-1.88	-3.38	-4.88	-6.50
14	96207	0.38	-0.25	-1.00	-2.25	-3.75	-5.38	-7.00
15	103409	0.25	-0.25	-1.25	-2.63	-4.25	-5.75	-7.50
16	93294	0.25	-0.38	-1.37	-2.88	-4.50	-6.13	-7.75
17	69975	0.25	-0.38	-1.38	-3.00	-4.75	-6.38	-8.00
18	16083	0.25	-0.38	-1.50	-3.00	-4.75	-6.38	-8.13

[a]The number of participants in each age group.

Table 2 Age-specific percentile distribution of refraction in children and adolescents by sex D

Age (y)	Boy			Girl		
	3rd	50th	97th	3rd	50th	97th
5	-1.50	0.25	1.25	-1.63	0.25	1.38
6	-1.88	0.13	1.25	-1.75	0.13	1.25
7	-2.38	0.00	1.00	-2.25	0.00	1.13
8	-3.13	-0.25	1.00	-3.12	-0.25	1.00
9	-3.88	-0.50	0.88	-3.88	-0.50	0.88
10	-4.50	-0.75	0.75	-4.63	-0.88	0.75
11	-5.24	-1.00	0.75	-5.38	-1.25	0.63
12	-5.75	-1.25	0.63	-6.00	-1.75	0.50
13	-6.38	-1.75	0.50	-6.50	-2.00	0.50
14	-7.00	-2.13	0.50	-7.00	-2.38	0.31
15	-7.50	-2.50	0.38	-7.50	-2.75	0.25
16	-7.75	-2.75	0.25	-7.75	-3.00	0.25
17	-8.00	-2.75	0.25	-8.00	-3.13	0.25
18	-8.12	-2.88	0.25	-8.13	-3.13	0.25
Total	-6.25	-0.88	0.88	-6.38	-1.00	0.88

Table 3 Age-specific percentile distribution of refraction in children and adolescents by region D

Age (y)	Urban			Rural		
	3rd	50th	97th	3rd	50th	97th
5	-1.38	0.31	1.25	-1.63	0.25	1.25
6	-1.75	0.13	1.25	-1.88	0.13	1.25
7	-2.38	-0.12	1.13	-2.38	0.00	1.13
8	-3.12	-0.25	1.00	-3.13	-0.25	1.00
9	-3.88	-0.50	0.88	-3.88	-0.50	0.88
10	-4.50	-0.75	0.75	-4.63	-0.75	0.75
11	-5.25	-1.13	0.75	-5.25	-1.13	0.75
12	-5.88	-1.50	0.62	-5.88	-1.50	0.62
13	-6.50	-1.88	0.50	-6.50	-1.88	0.50
14	-7.00	-2.25	0.38	-7.00	-2.25	0.38
15	-7.50	-2.63	0.25	-7.50	-2.63	0.38
16	-7.87	-2.88	0.25	-7.75	-2.81	0.25
17	-7.88	-3.00	0.25	-8.19	-3.00	0.25
18	-8.00	-3.00	0.25	-8.25	-3.00	0.25
Total	-6.25	-0.91	0.88	-6.37	-0.98	0.88

between 9 and 15y, and gradually declines after age 15. Table 4 presents the annual refractive changes at different percentiles. The age at which the maximum annual rate of refractive change occurs varies across percentiles. For the 3rd percentile, the maximum rate occurs at 8–9y; for the 10th percentile, the peak occurs at 9–10y; for the 25th percentile, the maximum rate occurs between 9 and 13y; and for the 50th percentile, it occurs between 11 and 15y. Lower percentiles reach their maximum annual rate of refractive change at earlier ages.

DISCUSSION

This study presents percentile curves of SER for children and adolescents aged 5–18y. Across all percentiles, SER progressively shifts toward myopia with increasing age, consistent with the expected trajectory of refractive development. In our study, the median SER at age 5 was +0.25 D for both boys and girls. This result is consistent with Truckenbrod *et al*[9], who reported 50th percentiles of +0.26 D for boys and +0.24 D for girls among 5-year-old German children, and with Peñaloza-Barbosa *et al*[11], who reported a median SER of +0.50 D among Portuguese children aged 6–8y. Refraction in children from our province shows minimal differences compared with European peers at age 5. However, substantial differences are observed in the progression of refractive error among children from different countries. Between ages 5 and 18, median SER progressed to -3.13 D in boys and -3.38 D in girls in our study. The total mean refractive change from ages 5 to 20 was -2.92 D in children of Republic of Korea, whereas in German children it was -0.57 D for boys and -0.67 D for girls. Refractive progression occurs more rapidly among children and adolescents in Asian countries compared

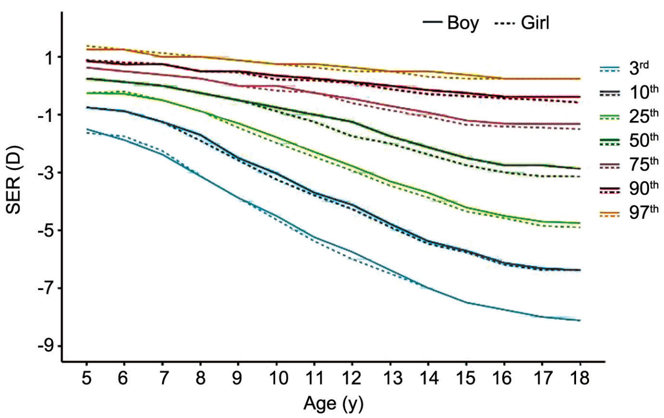

Figure 2 Age-specific percentile curves of SER by sex SER: Spherical equivalent refraction.

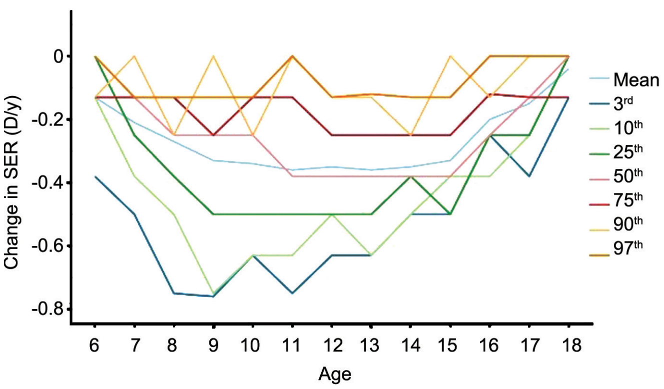

Figure 3 Annual refractive change (D/y) across percentiles by age "6" represents the changes in refractive error at ages 5 and 6, and so on. From ages 6 to 18, the mean annual rate of refractive change was -0.50 D/y for the 3rd percentile, -0.43 D/y for the 10th percentile, -0.25 D/y for the 50th percentile, -0.15 D/y for the 75th percentile, -0.10 D/y for the 90th percentile, and -0.08 D/y for the 97th percentile. Significant differences in annual refractive change rates were observed across percentiles, with lower percentiles exhibiting higher rates. For SER above the 50th percentile, the annual refractive change rate remained relatively stable at a slower rate, below -0.25 D/y. In contrast, for SER below the 50th percentile, the annual refractive change rate was faster, with the maximum progression reaching -0.76 D/y. SER: Spherical equivalent refraction.

with their European counterparts. Therefore, we speculate that the pronounced differences in myopia prevalence between Asian and European children are not attributable to innate refractive status but develop gradually during later stages of growth. Postnatal environmental factors, such as academic pressure, prolonged near-work, and insufficient outdoor activity, may be key contributors to the faster progression and higher prevalence of myopia observed in Asian children[17].

Percentile reference intervals for SER were generated using the GAMLSS model. With increasing age, SER showed an overall shift toward myopia, with lower percentiles exhibiting greater myopia and faster progression. Truckenbrod *et al*[9] and Kim *et al*[7] reported percentile curves for children in Germany

Table 4 Annual refractive change across ages and percentiles

Age (y)	Mean	97th	90th	75th	50th	25th	10th	3rd
6	-0.13	0.00	-0.13	-0.13	-0.13	0.00	-0.13	-0.38
7	-0.21	-0.13	0.00	-0.13	-0.13	-0.25	-0.38	-0.50
8	-0.27	-0.13	-0.25	-0.13	-0.25	-0.38	-0.50	-0.75
9	-0.33	-0.13	0.00	-0.25	-0.25	-0.50	-0.75	-0.76
10	-0.34	-0.13	-0.25	-0.13	-0.25	-0.50	-0.63	-0.63
11	-0.36	0.00	0.00	-0.13	-0.38	-0.50	-0.63	-0.75
12	-0.35	-0.13	-0.13	-0.25	-0.38	-0.50	-0.50	-0.63
13	-0.36	-0.12	-0.13	-0.25	-0.38	-0.50	-0.63	-0.63
14	-0.35	-0.13	-0.25	-0.25	-0.38	-0.38	-0.50	-0.50
15	-0.33	-0.13	0.00	-0.25	-0.38	-0.50	-0.38	-0.50
16	-0.20	0.00	-0.13	-0.12	-0.25	-0.25	-0.38	-0.25
17	-0.15	0.00	0.00	-0.13	-0.13	-0.25	-0.25	-0.38
18	-0.04	0.00	0.00	-0.13	0.00	0.00	0.00	-0.13

and Republic of Korea, showing comparable trends. Wu *et al*[18] conducted a one-year follow-up of 4292 students aged 6–12y and found that lower baseline refraction was associated with greater myopic progression. Further analysis of percentile differences across age groups revealed that girls had lower SER than boys, with gender differences becoming increasingly pronounced after age 10 (P<0.01). These gender differences may be attributable to girls entering puberty 1.5–2y earlier than boys, during which peak somatic growth is accompanied by accelerated axial elongation[19]. Additionally, behavioral factors may contribute to gender differences, as girls tend to be quieter, spend more time studying, and engage in less outdoor activity than boys[20]. Female is considered a risk factor for myopia development[21]. In this study, children from rural areas exhibited more myopic development than urban children, particularly at lower percentiles, in contrast to previous reports indicating higher myopia prevalence in urban populations[22-24]. Previous studies have reported that rural children have substantially reduced outdoor activity and increased screen time, leading to elevated myopia risk[25-28]. Conversely, urban families with higher income and parental education levels demonstrate greater awareness of myopia prevention and are more likely to implement effective myopia control interventions for their children[29]. Consequently, myopia prevalence among urban children has improved, resulting in a reversal of myopia rates between urban and rural populations. Therefore, residing in rural areas has emerged as a risk factor for myopia among children and adolescents.

Postnatal refractive development is a dynamic process, with substantial variability reported in patterns of refractive development among children across different studies. Previous studies often focused on narrow age ranges. In the present study, we report the annual refractive development curve for children aged 5–18y. The results indicate that refractive development follows a U-shaped trajectory. Before age 9, the annual refractive progression rate increases with age, peaks between 9 and 15y, and gradually declines thereafter. Variations in the timing of peak refractive progression have been reported in previous studies. Annual refractive progression is influenced by multiple factors, including age, ethnicity, gender, and baseline refractive status. Verkicharla *et al*[30] reported the highest annual myopic progression in Indian children aged 6–10y. Tricard *et al*[31] found that myopia progression was most rapid among children aged 7–9y. Wang *et al*[32] suggested that myopia progression accelerates sharply in second grade and decelerates by the eighth grade. Guo *et al*[33] found that the rate of refractive progression was highest among children aged 10–12y. The underlying factors contributing to prolonged myopic progression in Chinese school-aged children warrant further investigation.

Significant variation exists in annual refractive progression rates across different percentiles. The 3rd percentile reaches its peak annual progression rate of -0.75 D at age 7. The 25th percentile reaches a maximum progression rate of -0.50 D at age 8 and beyond, and the 50th percentile attains its peak progression rate of -0.38 D from age 10 onwards. The 75th percentile reaches a maximum progression rate of -0.25 D after age 11, and the 97th percentile peaks at -0.13 D after age 11. Overall, lower percentiles exhibit faster annual progression, with peak rates occurring at earlier ages. Studies by Li *et al*[34] and Zadnik *et al*[35] indicate that baseline SER is a strong predictor of myopia. Consequently, assessing a child's SER percentile allows prediction of refractive progression risk and facilitates tailored myopia prevention and control strategies. For children with SER at or above the 50th percentile, progression is relatively slow, and excessive preventive measures may yield limited additional benefit while increasing the economic burden of myopia management. Conversely, school-aged children with SER below the 50th percentile exhibit faster progression. Early intervention is warranted, and preventive measures should be strengthened for this high-risk group.

This study's strengths include comprehensive coverage of all 103 county-level administrative districts in Hubei Province, providing a representative sample. The study population spanned all school-age stages, from 5 to 18y. However, several limitations should be acknowledged. Cycloplegic refraction was not feasible due to the large sample size, potentially leading to overestimation of SER, especially in younger students. Future studies may incorporate ocular biometric measurements to enhance the accuracy of refractive assessments. Moreover, the cross-sectional data used to generate the percentile curves are specific to the study population, region, and study period, and therefore may not be generalizable to other countries. Being cross-sectional, the study cannot capture longitudinal refractive progression corresponding to specific percentiles. Hence, longitudinal cohort studies are warranted to further validate these findings.

In conclusion, we present percentile curves of refractive development for school-aged children aged 5–18y in Hubei Province, Central China. Children in lower percentiles exhibit faster myopic progression, indicating that intensified myopia prevention and control strategies are particularly warranted for this high-risk group.

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Data Availability Statement: The datasets generated and analyzed during the current study are not publicly available due to privacy and ethical restrictions but are available from the corresponding author on reasonable request.

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