Methods and Applications

Reference Values of Non-Cycloplegic Spherical Equivalent for Screening and Predicting Myopia Among Children and Adolescents — China, 2020-2024

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ABSTRACT

Introduction: Non-cycloplegic refraction is widely utilized in vision screening. However, interpreting non-cycloplegic refraction results remains a significant challenge in both clinical practice and public health settings. This study aimed to establish grade- and sex-specific reference values for non-cycloplegic spherical equivalent (SE) to enhance myopia screening and risk prediction among Chinese students.

Methods: A comprehensive study was conducted between 2020 and 2024, involving 67,260 students from kindergarten through high school across 10 provincial-level administrative divisions (PLADs) in China. The Lambda-Mu-Sigma method was employed to model non-cycloplegic SE. Reference values were established by calculating SE centiles corresponding to myopia and high myopia prevalence across grades 0 through 12.

Results: Among boys, the estimated prevalence of myopia and high myopia increased from 1.2% and <0.1% in grade 0 (senior kindergarten) to 82.4% and 11.6% in grade 12 (third year of high school), respectively. For twelfth-grade boys, the 82.4th and 11.6th percentiles of SE (–0.99 D and –6.16 D) were established as reference values for screening myopia and high myopia, respectively. The corresponding percentiles in lower grades served as predictive reference values for grade 12 outcomes. For instance, a grade-0 boy with non-cycloplegic SE>0.70 D (82.4th percentile) was predicted to remain free of myopia before grade 12. Similarly, SE>–0.73 D (11.6th percentile) indicated a low likelihood of developing high myopia before grade 12.

Conclusions: This study established comprehensive non-cycloplegic SE reference values for screening and predicting myopia among Chinese students. The methodology developed here may be applicable to other regions where student myopia prevalence patterns demonstrate relative stability.

Myopia represents a significant public health challenge. In China, myopia affected over 80% of high school students in 2018, with approximately one-fifth of myopic students developing high myopia (*1*). Early prediction of myopia risk, identification of susceptible individuals, and timely intervention are essential strategies to delay myopia onset and minimize the risk of high myopia progression (*2*). While cycloplegic spherical equivalent (SE) remains the gold standard for myopia diagnosis and provides more reliable predictive indicators, non-cycloplegic SE is predominantly used in public health screening programs due to cycloplegia's procedural complexity and potential adverse effects (*3*–*4*).

METHODS

The National Disease Control and Prevention Administration of China coordinated a nationwide hyperopia reserve survey across 10 provincial-level administrative divisions (PLADs) between 2020 and 2024: Beijing, Shanxi, Liaoning, Zhejiang, Shandong, Henan, Hunan, Guangdong, Chongqing, and Shaanxi. In most PLADs, two cities were selected based on economic development levels: one more developed and one less developed. Exceptions included Liaoning Province, where six cities were selected (three more developed, three less developed) based on per capita gross domestic product; Beijing and Chongqing, where two districts were selected (one more developed, one less developed); and Shandong Province, where two districts from a single city were selected (one more developed, one less developed). Students from senior kindergarten through high school were selected using a multistage cluster sampling design at each site. This study utilized the survey data to establish sex- and grade-specific reference values of non-cycloplegic SE from senior kindergarten (grade 0) through third-year

high school (grade 12).

Refraction measurements were conducted using identical desktop autorefractors for both non-cycloplegic and cycloplegic (0.5% tropicamide, administered 4 times at 5-minute intervals) conditions. Certified professionals performed all eye examinations to ensure measurement accuracy. Quality control measures included random retesting of 5% of participants at each survey site, with additional testing required if measurements differed by more than 0.5 D. Due to the high correlation between ocular parameters of both eyes, only right eye data are presented. SE was calculated by adding spherical power (D) to half the cylindrical power (D). Myopia was defined as cycloplegic SE≤–0.50 D, and high myopia as ≤ –6.00 D.

Statistical analyses were conducted using R software (version 4.2.2, R Foundation for Statistical Computing, Vienna, Austria). The non-cycloplegic SE data were modeled using the Lambda-Mu-Sigma (LMS) method, which assumes that non-cycloplegic SE values at each grade follow a normal distribution after Box-Cox power transformation. The $100\,\alpha$ percentile of non-cycloplegic SE at grade t ($C_{100\alpha}(t)$) was calculated using the following equation. In this equation, M(t) represents the median non-cycloplegic SE at grade t, S(t) denotes the coefficient of variation, and L(t) indicates the power of normal transformation. These three parameters were modeled as smooth functions of grade using P-splines implemented through the GAMLSS package in R. Z_α represents the z-score corresponding to the $100\,\alpha$ percentile of the standard normal distribution.

$$\begin{cases} C_{100\alpha}(t) = M(t)\left(1 + L(t) \times S(t) \times Z_\alpha\right)^{-L(t)}, L(t) \neq 0 \\ C_{100\alpha}(t) = M(t)\exp\left(S(t) \times Z_\alpha\right), L(t) = 0 \end{cases}$$

For each grade, we calculated the corresponding percentiles of non-cycloplegic SE based on the smoothed prevalence of myopia from grades 0 to 12 (Supplementary Table S1, available at https://weekly.chinacdc.cn/), which formed the basis for determining grade-specific reference values for screening and predicting myopia. For instance, given that the myopia prevalence among grade 12 boys was 82.4%, we selected the 82.4th percentile of non-cycloplegic SE as the reference value for screening myopia in grade 12 boys. Similarly, the 82.4 percentile of non-cycloplegic SE for boys in lower grades served as a reference value for predicting myopia development by grade 12. The same methodological approach was applied to establish reference values for screening and predicting high myopia.

RESULTS

A total of 62,482 students were included in the analysis. The sample comprised 30,188 (48.3%) boys and 28,957 (46.3%) students from economically more developed areas. The distribution across educational levels was: 14,290 (22.9%) kindergarten students, 41,385 (66.2%) primary school students, 3,985 (6.4%) middle school students, and 2,822 (4.5%) high school students. The flow diagram of the study population is presented in Supplementary Figure S1 (available at https://weekly.chinacdc.cn/).

Table 1 and Table 2 present the grade-specific reference values of non-cycloplegic SE for screening myopia in boys and girls, respectively, along their main diagonals. These reference values demonstrated a high screening accuracy of 91.4%, with 82.4% sensitivity and 94.6% specificity. Above the main diagonal, the tables show reference values at lower grades that predict myopia development at corresponding higher grades. A student whose non-cycloplegic SE exceeds the reference value is predicted to remain free of myopia until that grade. Below the main diagonal, the tables display predicted non-cycloplegic SE values through grade 12, assuming myopia onset at specific grades. Notably, girls' reference values above the main diagonal generally exceeded those of boys, while values below the main diagonal were typically lower for girls compared to boys.

Table 3 and Table 4 present the reference values for screening and predicting high myopia for boys and girls, respectively, from grades 4 through 12. Reference values for grades 0 through 3 were omitted due to insufficient high myopia prevalence (less than 0.1%) to establish reliable reference values. The reference values for high myopia showed minimal gender differences across all grades.

DISCUSSION

This study established sex- and grade-specific reference values for non-cycloplegic SE to screen and predict myopia and high myopia among Chinese students from senior kindergarten through the third grade of high school. We chose to organize reference values by grade rather than age because eye health screening programs are typically implemented at the school level, and research has shown that grade level

TABLE 1. Grade-specific reference values of non-cycloplegic SE for screening and predicting myopia in boys.

Grade	Percentiles of non-cycloplegic SE (D)												
	1.2	5.8	15.7	29.5	42.5	52.9	62.2	70.3	76.2	79.5	81.2	82.1	82.4
0	**−1.71**	−1.05	−0.58	−0.23	0.01	0.18	0.33	0.47	0.57	0.64	0.67	0.69	0.70
1	−1.91	**−1.21**	−0.72	−0.36	−0.11	0.07	0.23	0.37	0.48	0.54	0.58	0.60	0.61
2	−2.49	−1.64	**−1.06**	−0.64	−0.35	−0.14	0.04	0.20	0.32	0.40	0.44	0.46	0.47
3	−3.58	−2.37	−1.59	**−1.04**	−0.67	−0.41	−0.19	0.01	0.16	0.26	0.31	0.34	0.34
4	−4.88	−3.21	−2.19	−1.49	**−1.03**	−0.70	−0.42	−0.18	0.01	0.13	0.19	0.23	0.24
5	−6.05	−4.02	−2.79	−1.95	−1.39	**−1.00**	−0.68	−0.38	−0.16	−0.02	0.06	0.10	0.11
6	−7.07	−4.82	−3.42	−2.45	−1.81	−1.36	**−0.98**	−0.64	−0.38	−0.22	−0.13	−0.08	−0.07
7	−7.89	−5.53	−4.02	−2.96	−2.26	−1.76	−1.33	**−0.95**	−0.65	−0.47	−0.37	−0.32	−0.30
8	−8.43	−6.08	−4.53	−3.41	−2.66	−2.12	−1.66	−1.25	**−0.92**	−0.73	−0.62	−0.56	−0.54
9	−8.77	−6.47	−4.90	−3.76	−2.97	−2.41	−1.92	−1.47	−1.13	**−0.92**	−0.80	−0.74	−0.72
10	−9.02	−6.76	−5.18	−4.01	−3.20	−2.61	−2.10	−1.63	−1.27	−1.04	**−0.92**	−0.86	−0.83
11	−9.28	−7.01	−5.41	−4.21	−3.37	−2.77	−2.24	−1.75	−1.38	−1.14	−1.02	**−0.95**	−0.92
12	−9.59	−7.27	−5.63	−4.39	−3.53	−2.90	−2.35	−1.85	−1.46	−1.22	−1.09	−1.01	**−0.99**

Note: The percentiles in the column headings correspond to myopia prevalence among boys from senior kindergarten (grade 0) through third grade of high school (grade 12). Each row represents the estimated percentiles of non-cycloplegic SE for boys in that grade. Values in the main diagonal indicate grade-specific reference values for screening myopia. In each column, values above the main diagonal represent reference values at lower grades for predicting future myopia development at the corresponding higher grades. Values below the main diagonal represent predicted non-cycloplegic SE values through grade 12, assuming myopia onset occurs at a specific grade.
Abbreviation: SE=spherical equivalent.

TABLE 2. Grade-specific reference values of non-cycloplegic SE for screening and predicting myopia in girls.

Grade	Percentiles of non-cycloplegic SE (D)												
	1.0	5.4	16.0	32.3	47.6	58.7	67.5	75.0	80.4	83.5	85.1	86.4	87.7
0	**−1.73**	−1.05	−0.55	−0.15	0.12	0.31	0.45	0.59	0.70	0.76	0.80	0.84	0.87
1	−1.97	**−1.25**	−0.72	−0.31	−0.02	0.17	0.33	0.47	0.58	0.65	0.70	0.73	0.77
2	−2.58	−1.72	**−1.09**	−0.61	−0.27	−0.05	0.13	0.30	0.43	0.51	0.56	0.60	0.64
3	−3.70	−2.51	−1.69	**−1.06**	−0.63	−0.35	−0.13	0.08	0.24	0.35	0.40	0.45	0.51
4	−5.08	−3.44	−2.37	−1.57	**−1.04**	−0.69	−0.41	−0.16	0.04	0.17	0.24	0.30	0.37
5	−6.31	−4.29	−3.01	−2.06	−1.43	**−1.02**	−0.70	−0.40	−0.17	−0.02	0.06	0.13	0.21
6	−7.33	−5.06	−3.60	−2.54	−1.83	−1.37	**−1.00**	−0.67	−0.40	−0.24	−0.14	−0.06	0.02
7	−8.09	−5.71	−4.16	−3.01	−2.24	−1.73	−1.32	**−0.96**	−0.67	−0.48	−0.38	−0.29	−0.19
8	−8.57	−6.22	−4.63	−3.44	−2.62	−2.08	−1.64	−1.25	**−0.93**	−0.73	−0.62	−0.52	−0.42
9	−8.85	−6.61	−5.03	−3.81	−2.95	−2.38	−1.92	−1.50	−1.16	**−0.95**	−0.83	−0.72	−0.61
10	−9.02	−6.93	−5.38	−4.13	−3.25	−2.65	−2.16	−1.70	−1.34	−1.11	**−0.98**	−0.86	−0.74
11	−9.08	−7.18	−5.68	−4.43	−3.52	−2.89	−2.37	−1.88	−1.49	−1.24	−1.09	**−0.97**	−0.84
12	−9.10	−7.39	−5.96	−4.71	−3.77	−3.11	−2.56	−2.05	−1.62	−1.35	−1.20	−1.06	**−0.91**

Note: The percentiles in the column headings correspond to myopia prevalence among girls from senior kindergarten (grade 0) through third grade of high school (grade 12). Each row represents the estimated percentiles of non-cycloplegic SE for girls in that grade. Values in the main diagonal indicate grade-specific reference values for screening myopia. In each column, values above the main diagonal represent reference values at lower grades for predicting future myopia development at the corresponding higher grades. Values below the main diagonal represent predicted non-cycloplegic SE values through grade 12, assuming myopia onset occurs at a specific grade.
Abbreviation: SE=spherical equivalent.

exhibits a stronger correlation with myopia than age (5).

The reference values for predicting myopia onset by grade 12 are consistently higher for girls compared to boys, with this disparity diminishing as grade levels increase. In grades 0 to 3, girls' values average 0.17 D higher than boys', while by grade 11, this difference narrows to only 0.09 D. This pattern aligns with

TABLE 3. Grade-specific reference values of non-cycloplegic SE for screening and predicting high myopia in boys.

Grade	Percentiles of non-cycloplegic SE (D)								
	0.4	1.0	1.9	3.3	5.0	6.7	8.3	10.0	11.6
0	−2.13	−1.78	−1.52	−1.29	−1.11	−0.99	−0.89	−0.80	−0.73
1	−2.36	−1.99	−1.71	−1.47	−1.28	−1.15	−1.04	−0.95	−0.88
2	−3.05	−2.58	−2.24	−1.95	−1.72	−1.56	−1.44	−1.33	−1.24
3	−4.44	−3.72	−3.22	−2.80	−2.48	−2.26	−2.10	−1.95	−1.84
4	**−6.12**	−5.08	−4.38	−3.80	−3.37	−3.07	−2.85	−2.66	−2.51
5	−7.51	**−6.29**	−5.44	−4.74	−4.21	−3.86	−3.59	−3.36	−3.18
6	−8.64	−7.34	**−6.41**	−5.62	−5.03	−4.63	−4.32	−4.06	−3.85
7	−9.48	−8.16	−7.20	**−6.38**	−5.75	−5.32	−5.00	−4.72	−4.49
8	−9.98	−8.70	−7.75	−6.94	**−6.30**	−5.87	−5.53	−5.25	−5.02
9	−10.26	−9.03	−8.11	−7.32	−6.69	**−6.26**	−5.92	−5.63	−5.40
10	−10.46	−9.27	−8.38	−7.60	−6.98	−6.55	**−6.22**	−5.92	−5.69
11	−10.70	−9.53	−8.65	−7.86	−7.24	−6.80	−6.46	**−6.17**	−5.93
12	−11.02	−9.84	−8.94	−8.14	−7.51	−7.06	−6.71	−6.41	**−6.16**

Note: The percentiles in the column headings correspond to the prevalence of high myopia among boys from grade 4 (fourth grade of primary school) through grade 12 (third grade of high school). Each row represents the estimated percentiles of non-cycloplegic SE for boys in that grade. Values in the diagonal represent grade-specific reference values for screening high myopia. In each column, values above the diagonal represent reference values at lower grades for predicting future high myopia development at the corresponding higher grades. Values below the diagonal represent predicted non-cycloplegic SE values through grade 12, assuming high myopia onset occurs at a specific grade.
Abbreviation: SE=spherical equivalent.

TABLE 4. Grade-specific reference values of non-cycloplegic SE for screening and predicting high myopia in girls.

Grade	Percentiles of non-cycloplegic SE (D)								
	0.4	0.9	1.6	2.8	4.6	6.6	8.6	10.8	13.2
0	−2.08	−1.76	−1.54	−1.32	−1.12	−0.96	−0.84	−0.74	−0.64
1	−2.33	−1.99	−1.77	−1.53	−1.32	−1.16	−1.04	−0.93	−0.83
2	−3.02	−2.61	−2.34	−2.05	−1.80	−1.61	−1.46	−1.33	−1.21
3	−4.35	−3.75	−3.36	−2.97	−2.62	−2.37	−2.17	−2.00	−1.84
4	**−6.02**	−5.14	−4.60	−4.05	−3.59	−3.25	−2.99	−2.77	−2.57
5	−7.49	**−6.39**	−5.72	−5.05	−4.48	−4.07	−3.76	−3.49	−3.25
6	−8.62	−7.42	**−6.66**	−5.90	−5.27	−4.80	−4.45	−4.15	−3.88
7	−9.41	−8.18	−7.40	**−6.61**	−5.94	−5.44	−5.06	−4.74	−4.45
8	−9.84	−8.66	−7.90	−7.12	**−6.45**	−5.95	−5.56	−5.23	−4.94
9	−10.03	−8.93	−8.22	−7.48	−6.83	**−6.35**	−5.97	−5.64	−5.34
10	−10.06	−9.09	−8.44	−7.76	−7.14	−6.68	**−6.30**	−5.98	−5.69
11	−9.98	−9.15	−8.58	−7.95	−7.38	−6.94	−6.59	**−6.27**	−5.98
12	−9.87	−9.16	−8.66	−8.10	−7.58	−7.16	−6.83	−6.53	**−6.25**

Note: The percentiles in the column headings correspond to the prevalence of high myopia among girls from grade 4 (fourth grade of primary school) through grade 12 (third grade of high school). Each row represents the estimated percentiles of non-cycloplegic SE for girls in that grade. Values in the diagonal represent grade-specific reference values for screening high myopia. In each column, values above the diagonal represent reference values at lower grades for predicting future high myopia development at the corresponding higher grades. Values below the diagonal represent predicted non-cycloplegic SE values through grade 12, assuming high myopia onset occurs at a specific grade.
Abbreviation: SE=spherical equivalent.

previous research documenting that girls experience more rapid SE decline and higher myopia susceptibility than boys (*6*). These sex-based differences may be attributed to variations in near-work activities, outdoor exposure, and pubertal timing between boys and girls (*7*–*8*).

In a parallel study using identical methodology, we established cycloplegic SE reference values and observed that non-cycloplegic SE reference values were consistently lower than their cycloplegic counterparts, though this difference decreased with advancing grade levels. For grade 0 students, the discrepancy between cycloplegic and non-cycloplegic reference values for predicting myopia-free status by grade 12 was 0.84 D for boys and 0.93 D for girls. By grade 11, these differences diminished to 0.49 D and 0.41 D for boys and girls, respectively. These findings corroborate previous research demonstrating that the disparity between cycloplegic and non-cycloplegic refractive measurements is inversely related to age and myopic refractive error (*9*).

This study represents the first comprehensive effort to establish reference values for non-cycloplegic SE in predicting myopia using a methodology originally developed for body mass index assessment of thinness, overweight, and obesity in children (*10*–*11*). While our study introduces this novel approach and establishes reference values based on an extensive nationwide dataset with broad geographic coverage, several limitations warrant consideration. First, the participant sampling was not strictly randomized, and certain significant myopia-associated factors — including parental refractive error, eye care practices, and environmental lighting conditions — were not fully accounted for. Additionally, the timing of refractive measurements varied between morning (before classes) and afternoon (after prolonged study periods), with afternoon measurements typically showing greater myopic tendencies. Furthermore, the constant accommodation in younger students' eyes during non-cycloplegic refractive testing may introduce measurement errors, potentially affecting the predictive accuracy of reference values for lower-grade students. Nevertheless, the screening accuracy remained robust, exceeding 87.3% for myopia and 97.1% for high myopia across all grades.

The reference values proposed in this study offer valuable guidance for myopia screening and prediction in both public health initiatives and clinical settings, facilitating early identification and intervention for individuals at elevated risk for myopia. Moreover, the methodology employed here has potential applications beyond China in settings where childhood and adolescent myopia prevalence patterns demonstrate relative stability.

Conflicts of interest: No conflicts of interest.

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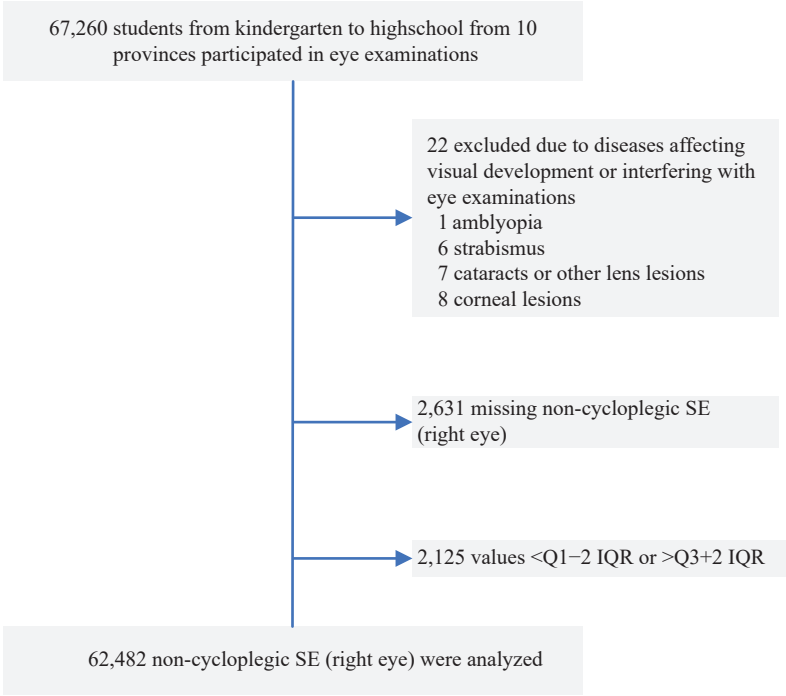
SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Estimated prevalence of myopia and high myopia at grade 0 to 12.

Grade	Myopia (%)			High myopia (%)		
	Total	Boy	Girl	Total	Boy	Girl
0	1.1	1.2	1.0	<0.1	<0.1	<0.1
1	5.5	5.8	5.4	<0.1	<0.1	<0.1
2	15.5	15.7	16.0	<0.1	<0.1	<0.1
3	31.0	29.5	32.3	<0.1	<0.1	<0.1
4	45.4	42.5	47.6	0.4	0.4	0.4
5	55.5	52.9	58.7	0.9	1.0	0.9
6	64.5	62.2	67.5	1.6	1.9	1.6
7	73.3	70.3	75.0	3.0	3.3	2.8
8	79.5	76.2	80.4	5.0	5.0	4.6
9	82.3	79.5	83.5	6.8	6.7	6.6
10	83.4	81.2	85.1	8.4	8.3	8.6
11	84.0	82.1	86.4	10.1	10.0	10.8
12	84.2	82.4	87.7	11.6	11.6	13.2

Note: The prevalence of myopia and high myopia at each grade was estimated using the Lambda-Mu-Sigma (LMS) method to determine the percentiles corresponding to –0.50 D and –6.00 D in the cycloplegic spherical equivalent (SE) for each grade. Complete methodological details regarding the estimation of smoothed myopia prevalence will be presented in a forthcoming study.



SUPPLEMENTARY FIGURE S1. Flow diagram of study population
Note: To minimize the impact of extreme outliers, we excluded values falling below Q1–2 IQR or above Q3+2 IQR from the analyses, where Q1 and Q3 represent the first and third quartiles of the grade-specific sample data, and IQR represents the interquartile range (Q3–Q1). This exclusion criterion resulted in the removal of 3.2% of observations.
Abbreviation: SE=spherical equivalent.