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Prevalence and association of uncorrected refractive error among Chinese adolescents: a cross-sectional study

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Abstract

Background Uncorrected refractive error (URE) is one of the main causes of visual impairments. URE may reduce interaction and learning in the classroom, leading to social isolation, irreversible amblyopia, lack of external knowledge, and restrictions on education and employment opportunities. Our aim was to investigate the prevalence and related factors of URE in adolescents using epidemiological surveys and questionnaire surveys related to lifestyle habits.

Methods A cross-sectional school-based study was conducted in Nantong, China, including adolescents 12–19 years of age from 16 schools. URE was defined as presenting visual acuity worse than 6/12 and improving to ≥ 1 lines after correction in either eye. Univariate and multivariate logistic regression analyses were used to investigate specific correlations between URE and related lifestyle parameters. Non-cycloplegic autorefraction was assessed for each adolescent.

Results A total of 2,910 adolescents were analyzed, of which 50.3% ($n = 1,465$) were male, and 49.7% ($n = 1,445$) were female. The mean age was 15.23 ± 1.77 years. The overall prevalence of URE was 23.7%. The total prevalence of REC and eREC was 85.1% and 71.7%, respectively, and both of them showed an increasing trend with age (Ptrend = 0.018 and Ptrend = 0.019, respectively). A higher prevalence of URE was related to myopia, anisometropia, and increased daily use of electronic products. Timely visual examination by medical institutions, more extracurricular homework, and older age were protective factors for URE. Among the 689 adolescents with URE, 362 (52.5%) did not receive any refractive correction, and 327 (47.5%) used corrected glasses.

Conclusion URE was highly prevalent among adolescents in China. Myopia was the most important risk factor for URE. The impact of anisometropia and increased daily use of electronic devices on URE was significant. Timely visual examinations by medical institutions served as an effective protective factor against URE. Further research on adjusting intervention strategies is therefore needed to eliminate preventable visual impairments.

Keywords Uncorrected refractive error, Adolescent, Lifestyle, Myopia, Anisometropia

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Background

Uncorrected refractive error (URE) is one of the main causes of visual impairments (VIs) [1], and it is the leading cause for moderate to severe VI globally, and the second most common cause for blindness [2]. The Global Burden of Disease study in 2013 showed that among eye diseases, URE had the greatest burden, followed by cataracts, suggesting that URE remained a major challenge [3]. The World Health Organization has estimated that approximately 12.8 million children and adolescents (ages: 5–15 years) are visually impaired due to URE, with half living in China [4]. For children and adolescents, URE has a wide range of social and economic impacts globally. The poor visual experience caused by URE may reduce interaction and learning in the classroom, leading to social isolation, irreversible amblyopia, lack of external knowledge, and restrictions on education and employment opportunities [5–7].

URE is frequently disregarded because ophthalmologists' practices tend to prioritize the medical management of patients with diminished vision and ocular diseases [8, 9]. From Vision 2020, the World Health Organization has identified URE as one of the five priority areas, and emphasized the need to direct special attention to URE in children and developing countries [10]. The prevalence of URE among children in developing and developed countries reported in the Children's Refractive Error Study ranged from 3–7% [11]. In a recent Global Burden of Disease study on the prevalence and causes of uncorrected refractive errors in children, Cao et al. [12] found that many countries lacked research, and many studies used different URE detection standards. Given that presenting visual acuity (PVA) is incorporated in the evaluation of URE, URE considers refractive errors that could be linked to absent, incorrect, or outdated corrective measures [8]. Prevalence data are crucial for determining service needs and indicates which groups should be targeted for interventions in future planning. It provides key baseline information for achieving the World Health Organization's goal of increasing effective coverage of refractive errors by 40% by 2030 [13].

China has the second-largest adolescent group in the world, representing 11.5% of the total population in China [14]. However, previous studies on URE in Chinese children and adolescents have been inadequate. Many key risk factors that form the basis of major non-communicable diseases typically begin or increase during adolescence [15], while over the years, the unique health issues of adolescents have been rarely understood, or in some cases, overlooked [16]. Lifestyle (LS) is the way in which people or groups experience reality and make choices, which are determined by social, economic, cultural, and environmental factors. It encompasses a set of habits and customs that affect the health-disease process [17]. Because LS is an easily changeable factor and has been fully proven to be related to adolescents' visual refractive states [18], it is worth determining whether LS contributes to the development of URE.

Specifically in this analysis we (1) estimated the prevalence of any URE among Chinese adolescents and (2) described the risk associations between LS risk factors with any URE. We also discussed the prevalence and influencing factors of URE using various definitions.

Methods

Survey and data collection

This was a population-based cross-sectional study, the second Affiliated Hospital of Nantong University conducted eye examinations for high school adolescents during June 2022. The protocol and consent procedures were approved by the ethics committee of the Second Affiliated Hospital of Nantong University, China (approval number: 2020KT068). All protocols used in this study followed the tenets of the Declaration of Helsinki [19]. Previous studies have shown that the prevalence of URE was approximately 15.5% in school-aged children in Shanghai, China [20]. To achieve a power of 80%, the sample size was calculated using the formula, $n=t^2pq/d^2$, assuming a design effect of 1.5 due to cluster sampling and a nonresponse of 5% [t=2 for a 95% confidence interval (CI), q=1-P, d=0.1 P]. The total sample size was at least 2,180. To ensure better multifactor analyses, more samples were included in the protocol.

All junior and senior high schools (16 schools) participated in this study in the urban area of Nantong, China. At least two classes were randomly selected from each grade of each school to ensure that no less than 80 adolescents were selected at a time. The investigators arranged a meeting with the class director, the adolescents, and at least one guardian before recruitment to explain the objectives and procedures of the study. After explaining the nature of the study, written informed consent was obtained from each adolescent, corresponding guardian, or the class director, and we promised to keep their information confidential. All adolescents and their guardians completed a detailed questionnaire at the classroom with the help of a well-trained investigator. Five optometrists, two public health doctors, and four ophthalmologists formed an executive team. An experienced pediatric ophthalmologist served as the project coordinator and was responsible for the entire investigation process.

Questionnaire data

According to relevant requirements of the "National Monitoring and Intervention Plan for Common Diseases and Health Influencing Factors among adolescents," advice was obtained about the questionnaire from experts engaged in refractive diseases and

epidemiological research. We developed the questionnaire in Supplementary Table 1 (Table-S1). It included questions about age, height, weight, and sex. Some of the questions included whether adolescents were born prematurely, feeding status during childhood, preference for sweet foods, preference for carbonated drinks, parents' reminders about adolescents' poor daily reading and writing posture (approximately every week), teachers' reminders about adolescents' reading and writing posture (approximately every week), where students mainly stayed during class intervals (classroom or outdoor), whether adolescents notified their parents when they noticed a decrease in their vision, whether their parents took them for examinations by medical institutions when they found that their child's eyesight had decreased, average daily sleep time, average daily homework time, average daily mobile phone or iPad use, average TV time per week, daily outdoor activity, the times of rests after close work, normal reading distance, seat in the classroom, the number of annual visual examinations at school, and parental myopia. The formula "[(hours spent on a weekday) × 5 + (hours spent on a weekend day) × 2 divided by 7]" was used to calculate the mean number of hours spent outdoors each day. Similar calculation methods were used for daily sleep times, times spent on homework after class every day, and daily mobile phone or iPad use times.

Definitions

According to the International Myopia Institute (IMI) guidelines [21], myopia was defined a spherical equivalent (SE) of ≤ -0.5 D. Low myopia was defined as SE>-6.00 and ≤-0.50.High myopia was defined as an SE ≤ -6.0 D. Anisometropia was defined as the SE difference ≥ 1.0 D between eyes. Astigmatism was the absolute value of a cylinder ≥ 1.0 D. To minimize the potential impact of spurious associations between anisometropia and ametropic, subjects were categorized according to the SE in less ametropic eyes [22].

PVA defined as vision in normal daily life conditions, whether corrected or not, was the outcome variable. URE was defined as PVA worse than 6/12 and improving to ≥1 lines after correction in either eye [23]. Our definition of URE was based on the validated refractive correction threshold from the study of pediatric refractive errors [24, 25]. We also explored other definitions of URE. Diagnostic criteria 2 was URE (URE2): PVA in the better-seeing eye was worse than 6/12 and when visual acuity improved more than 1 line with refractive correction in the better-seeing eye [9].

The definition of Effective Refractive Error Coverage (eREC) (%) was calculated as [26]: eREC (%) = [(met need)/(total need)] × 100. Refractive Error Coverage (REC) (%) was calculated as: REC (%) = (met need+under-met need)/(total need) × 100. Participants who wore spectacles and had distance VA worse than 6/12 in either eye without correction but achieved 6/12 or better with their own spectacles were designated as "met need." "Under-met need" was defined as PVA worse than 6/12 with their present spectacles and could achieve 6/12 or better with correction. "Unmet need" was defined as the participants who had VA worse than 6/12 in either eye without correction and could achieve 6/12 or better with correction but did not wear spectacles. The sum of "met need," "unmet need," and "under-met need" was considered as "total need."

VA assessment

Well-trained investigators performed eye examinations. If adolescents wore glasses on a regular basis, they were required to bring their glasses to the ophthalmic examination site in advance. Vision measurement started with the right eye. PVA was measured by a standard logarithmic liquid crystal tumbling E chart (WSVC-100; Qingdao Optometry, Berkeley, CA, USA) at 5 m. Three repeated measurements used an autorefractor (WSRMK-8000; Biobase, Shandong, China). If any two of the measurements were greater than 0.50 D (diopters), additional checks were conducted. The average value of the three measurements was then analyzed. The best-corrected visual acuity (BCVA) was corrected according to the autorefractor results. Refinement of the sphere, cylinder, and axis was done to achieve the BCVA. The SE refraction was calculated as the sum of the sphere power and half of the cylinder power, and visual acuity was converted into the logarithmic expression of minimum resolution angle for recordings.

The inclusion criteria were participants with complete socio-demographic, clinical examination data, and questionnaire results. Exclusion criteria applied to school-aged children with incomplete data. Any withdrawal from the study was accepted.

Statistical analyses

Data were analyzed using SPSS statistical software for Windows, version 22 (SPSS, Chicago, IL, USA). The differences between groups in terms of URE and parameters were compared using chi-square or independent *t*-tests, as appropriate. Univariate and multivariate logistic regression analyses were used to determine specific correlations between URE and related parameters. The odds ratio (OR) and 95% confidence interval (CI) for the associated factors were calculated. Cohen's kappa coefficient analysis was used to calculate the consistency of results using two classification criteria for URE. Continuous variables are expressed as the mean ± standard deviation, and categorical variables are expressed as percentages. The polynomial linear correlation in one-way analysis

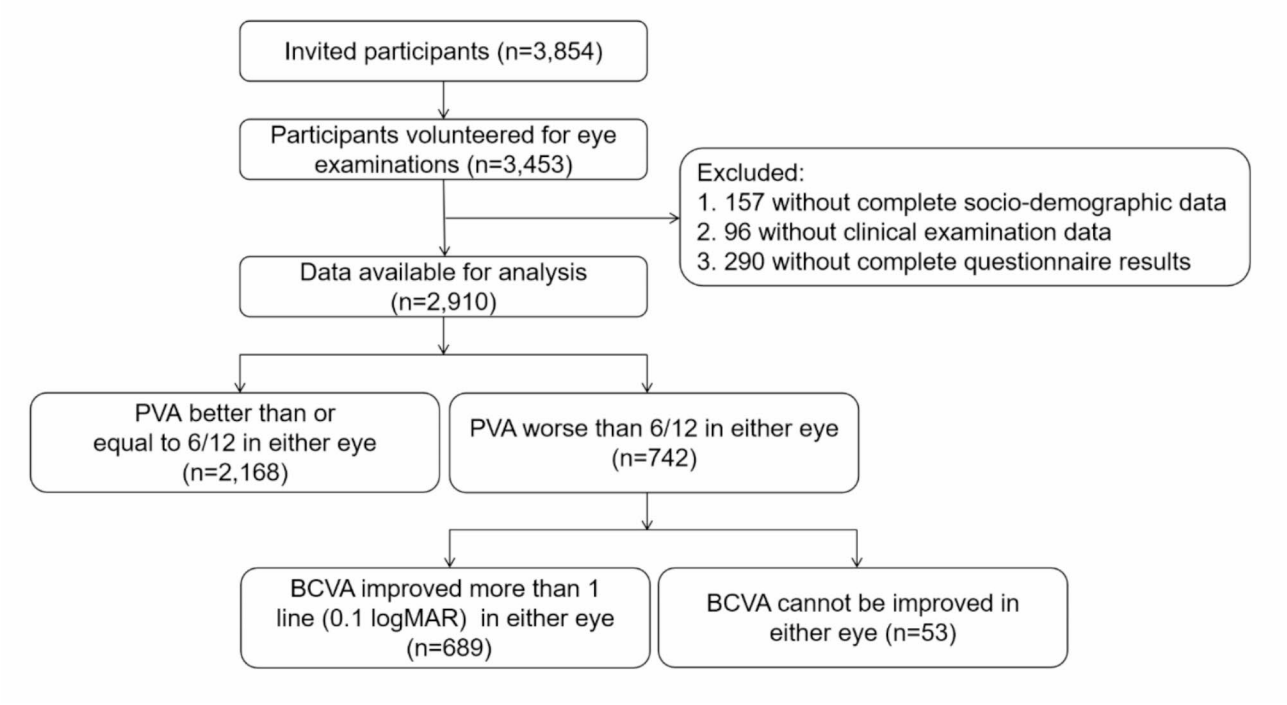


Fig. 1 Flow diagram of studied population. PVA: presenting visual acuity; BCVA: best-corrected visual acuity; logMAR: the logarithm of the minimum angle of resolution

Table 1 Prevalence of uncorrected refractive error, myopia, anisometropia, refractive error coverage and effective refractive error coverage among overall participants stratified by age

Age	*n*	Prevalence of URE	Prevalence of URE2	Prevalence of myopia	Prevalence of anisometropia	SE of the less ametropic eye (D)	REC	eREC
12	191 (6.6)	32.5%	10.5%	95.8%	33.0%	−3.52 ± 2.17	76.7%	57.5%
13	434 (14.9)	27.4%	9.4%	95.2%	30.0%	−3.45 ± 2.12	80.8%	64.4%
14	408 (14.0)	26.7%	6.6%	96.6%	33.6%	−3.55 ± 2.04	82.8%	64.4%
15	451 (15.5)	24.8%	11.1%	96.2%	35.9%	−3.98 ± 2.36	83.3%	70.3%
16	642 (22.1)	19.2%	7.3%	95.8%	34.3%	−4.15 ± 2.25	89.1%	70.3%
17	503 (17.3)	19.7%	8.7%	98.0%	30.2%	−4.43 ± 2.30	89.4%	77.8%
18	242 (8.3)	21.5%	9.1%	97.5%	35.5%	−4.22 ± 2.13	85.1%	75.0%
19	39 (1.3)	33.3%	17.9%	100.0%	23.1%	−4.21 ± 2.02	86.5%	64.9%
Total	2,910 (100.0%)	23.7%	8.9%	96.5%	33.0%	−3.95 ± 2.24	85.1%	71.7%
χ2 (F)		4.07	2.04	4.89	0.75	15.80	5.57	5.46
P-value		0.000	0.153	0.027	0.388	0.000	0.018	0.019

Results of the chi-square test for the trend test (Ptrend)

Abbreviations: URE: uncorrected refractive error; URE2: uncorrected refractive error diagnosed according to criterion 2; SE: spherical equivalent; REC, refractive error coverage; e-REC: effective refractive error coverage

of variance was used for the trend test (Ptrend). A value of $P<0.05$ was considered statistically significant. The parameters were calculated separately based on the diagnostic criteria for the two types of URE.

Results

A total of 3,854 adolescents were invited to participate in the study, and 3,453 adolescents volunteered for eye examinations. Of the 3,453 participants, 157 were excluded due to incomplete socio-demographic data, 96 were excluded due to incomplete clinical examination data, and 290 were excluded due to incomplete questionnaire results. Finally, 2,910 participants completed the entire survey, of which 50.3% ($n=1,465$) were male, and 49.7% ($n=1,445$) were female. A flow diagram of the study population is shown in Fig. 1.

The mean age of the participants was 15.23 ± 1.77 years (range: 12–19 years). As shown in Table 1, the overall prevalence of URE was 23.7%, and the prevalence of URE gradually decreased with age (Ptrend < 0.001). The

total prevalence of REC and eREC was 85.1% and 71.7%, respectively, and both of them showed an increasing trend with age (Ptrend=0.018 and Ptrend=0.019, respectively). At the age of 12 years, the mean SE of the less ametropic eye was −3.52±2.17 D, and as they aged, the mean SE of the less ametropic eye gradually transitioned to -4.21±2.02 D (Ptrend<0.001). The overall prevalences of myopia, URE2, and anisometropia were 96.5%, 8.9%, and 33.0%, respectively, and they did not show a trend of change with age (all, Ptrend>0.05). Cohen's kappa coefficient obtained from classifying URE according to the two different standards was 0.465, $P<0.001$, with moderate consistency.

As shown in Table 2, URE was related to sex, refractive state, anisometropia, teachers' reminders about poor daily reading and writing posture, and whether parents took the participants to medical institutions for examinations when they found that the child's eyesight had decreased, daily sleep time, time spent on homework every day, time spent on using a mobile phone or iPad every day, daily outdoor activity, seating location in the classroom, age, and height (all, $P<0.05$). URE2 was related to refractive state, daily sleep time, time spent on homework every day, time spent on using a mobile phone or iPad every day, daily outdoor activity, seats in the classroom, and height (all, $P<0.05$).

Table 3 lists the results of univariate and multiple logistic regression analyses. After adjustment for other characteristics, the results suggested that compared with adolescents without myopia, adolescents with low myopia were 4.07 times more likely to suffer from URE (aOR: 4.02, 95% CI: 2.42–6.67, $P<0.001$), and adolescents with high myopia were 4.45 times more likely to suffer from URE (aOR: 4.45, 95% CI: 2.06–9.61, $P<0.001$). Compared with adolescents without anisometropia, adolescents with anisometropia were 1.92 times more likely to suffer from URE (aOR: 1.92, 95% CI: 1.59–2.31, $P<0.001$). When parents found that an adolescent's eyesight decreased, timely examinations at medical institutions reduced 31% of the occurrences of URE (aOR: 0.69, 95% CI: 0.55–0.88, $P=0.003$). Compared to working less than 1 h per day, working 2–3 h per day reduced the URE by 48% (aOR: 0.52, 95% CI: 0.36–0.72, $P<0.001$). Working more than 4 h per day reduced the URE by 45% (aOR: 0.55, 95% CI: 0.37–0.77, $P<0.001$). Compared with using a mobile phone or iPad for less than 0.5 h per day, adolescents who used a mobile phone or iPad for more than 2 h per day were 1.52 times more likely to suffer from URE (aOR: 1.52, 95% CI: 1.12–2.07, $P=0.008$). In addition, older age was a protective factor for URE (aOR: 0.87, 95% CI: 0.82–0.93, $P<0.001$).

After adjustments for other characteristics, the results suggested that compared with adolescents without myopia, adolescents with low myopia were 13.24 times more likely to suffer from URE2 (aOR: 13.24, 95% CI: 1.82−96.45, $P=0.011$), adolescents with high myopia were 22.57 times more likely to suffer from URE2 (aOR: 22.57, 95% CI: 3.04–167.29, $P=0.002$). Compared with adolescents without anisometropia, anisometropia reduced URE2 by 28% (aOR: 0.72, 95% CI: 0.54–0.97, $P=0.031$). In addition, compared to working less than 1 h per day on homework, working 2–3 h per day reduced URE2 by 49% (aOR: 0.51, 95% CI: 0.32–0.82, $P=0.006$), and working 3–4 h per day reduced URE2 by 38% (aOR: 0.62, 95% CI: 0.37–1.04, $P=0.071$).Compared with using a mobile phone or iPad for less than 0.5 h per day, adolescents who used a mobile phone or iPad for 1.5–2 h per day were 1.58 times more likely to suffer from URE2 (aOR: 1.58, 95% CI: 0.87–2.19, $P=0.044$).

Among all 2,910 adolescents, eight used rigid gas permeable contact lenses for refractive correction. Regardless of either URE criterion, all eight adolescents were excluded from URE. Other adolescents who have undergone refractive correction used glasses for correction. There were 689 adolescents with URE. As shown in Figs. 2 and 362 (52.5%) adolescents did not undergo any refractive correction, whereas 327 (47.5%) adolescents underwent refractive corrections using glasses. When classified according to refractive state, among participants with low myopia, URE without refractive correction was more common (62.0%). Among participants with high myopia, wearing glasses for refractive correction was more common (86.0%). When classified according to diagnostic criterion 2, there were 258 adolescents with URE2. As shown in Figs. 3 and 139 (53.9%) adolescents did not have refractive correction, while 119 (46.1%) adolescents had refractive corrections using glasses. When classified according to refractive state, among participants with low myopia, URE2 without refractive correction was more common (64.1%). Among participants with high myopia, wearing glasses for refractive correction was more common (76.9%).

Discussion

In the current research, we found that the prevalence of URE among high school adolescents in China was as high as 23.7%. A higher prevalence of URE was related to myopia, anisometropia and more daily use of electronic products. Timely visual examinations by medical institutions, more extracurricular homework, and older age were protective factors for URE. In addition, the prevalences of REC and eREC among Chinese high school students was 85.1% and 71.7%, respectively.

Children and adolescents are a vulnerable group. The key public health challenges presented by URE requires urgent attention. The series of the Refractive Error Study in Children conducted among people of different ethnic and cultural backgrounds showed that URE had extensive

Table 2 Characteristics of participants

Characteristic	Total (*n* = 2,910)	Diagnosed as URE (*n* = 689)	Diagnosed as non-URE (*n* = 2,221)	Diagnosed as URE according to criterion 2 (*n* = 258)	Diagnosed as non-URE according to criterion 2 (*n* = 2,652)	*P*-value[a]	*P*-value[b]
Sex, *n* (%)						0.005	0.070
Male	1,465 (50.3)	315 (45.7)	1,150 (51.8)	116 (45.0)	1,349 (50.9)		
Female	1,445 (49.7)	374 (54.3)	1,071 (48.2)	142 (55.0)	1,303 (49.1)		
Refractive state, n (%)						**0.001**	**0.001**
Non myopia	103 (3.5)	8 (1.2)	95 (4.3)	1 (0.4)	102 (3.8)		
Low myopia	2259 (77.6)	545 (79.1)	1714 (77.2)	192(74.4)	2067(77.9)		
High myopia	548 (18.8)	136 (19.7)	412 (18.6)	65 (25.2)	483 (18.2)		
Anisometropia, n (%)						**0.000**	**0.052**
Yes	959 (33.0)	300 (43.5)	659 (29.7)	71 (27.5)	888 (33.5)		
No	1,951 (67.0)	389 (56.5)	1,562 (70.3)	187 (72.5)	1,764 (66.5)		
Born prematurely, n (%)						**0.753**	**0.712**
Yes	220 (7.6)	54 (7.8)	166 (7.5)	21 (8.1)	199 (7.5)		
No	2,690 (92.4)	635 (92.2)	2,055 (92.5)	237 (91.9)	2,453 (92.5)		
Feeding status in childhood, n (%)						**0.369**	**0.668**
Breast feeding	671 (23.1)	168 (24.4)	503 (22.6)	63 (24.4)	608 (22.9)		
Mixed feeding	1,835 (63.1)	422 (61.2)	1,413 (63.6)	154 (59.7)	1,681 (63.4)		
Formula feeding	336 (11.5)	78 (11.3)	258 (11.6)	34 (13.2)	302 (11.4)		
Other types of infant feeding	68 (2.3)	21 (3.0)	47 (2.1)	7 (2.7)	61 (2.3)		
Preference for sweet foods, n (%)						**0.942**	**0.227**
Yes	2,134 (73.3)	506 (73.4)	1,628 (73.3)	181 (70.2)	1,953 (73.6)		
No	776 (26.7)	183 (26.6)	593 (26.7)	77 (29.8)	699 (26.4)		
Preference for carbonated drinks, n (%)						**0.125**	**0.263**
Yes	1,641 (56.4)	406 (58.9)	1,235 (55.6)	154 (59.7)	1,487 (56.1)		
No	1,269 (43.6)	283 (41.1)	986 (44.4)	104 (40.3)	1,165 (43.9)		
You often hear parents' reminders about your poor daily reading and writing posture (approximately every week), n (%)						**0.480**	**0.511**
Yes	2,463 (84.6)	589 (85.5)	1,874 (84.4)	222 (86.0)	2,241 (84.5)		
No	447 (15.4)	100 (14.5)	347 (15.6)	36 (14.0)	411 (15.5)		
You often hear teachers' reminders about your poor daily reading and writing posture (approximately every week), n (%)						**0.043**	**0.109**
Yes	2,157 (74.1)	589 (85.5)	1,874 (84.4)	202 (78.3)	1,955 (73.7)		
No	753 (25.9)	100 (14.5)	347 (15.6)	56 (21.7)	697 (26.3)		
Where do you mainly stay during class intervals, n (%)						**0.750**	**0.319**
Classroom	2,030 (69.8)	484 (70.2)	1,546 (69.6)	187 (72.5)	1,843 (69.5)		
Outdoors	880 (30.2)	205 (29.8)	675 (30.4)	71 (27.5)	809 (30.5)		
When you notice a decrease in your eyesight, you will inform your parents, n (%)						**0.135**	**0.178**
Yes	2,516 (86.5)	560 (81.3)	1,956 (88.1)	216 (83.7)	2,300 (86.7)		
No	394 (13.5)	129 (18.7)	265 (11.9)	42 (16.3)	352 (13.3)		
If your parents realize that your eyesight has decreased, they will take you to medical institution for examination in a timely manner, n (%)						**0.000**	**0.370**
Yes	2,394 (82.3)	526 (76.3)	1,868 (84.1)	207 (80.2)	2,187 (82.5)		
No	516 (17.7)	163 (23.7)	353 (15.9)	51 (19.8)	465 (17.5)		
Daily sleep time, n (%)						**0.007**	**0.010**
< 6 h	576 (19.8)	108 (15.7)	468 (21.1)	34 (13.2)	542 (20.4)		
6 ~ 7 h	1,477 (50.8)	355 (51.5)	1,122 (50.5)	131 (50.8)	1,346 (50.8)		
7 ~ 8 h	683 (23.5)	176 (25.5)	507 (22.8)	71 (27.5)	612 (23.1)		
8 ~ 9 h	149 (5.1)	40 (5.8)	109 (4.9)	17 (6.6)	132 (5.0)		
> 9 h	25 (0.9)	10 (1.5)	15 (0.7)	5 (1.9)	20 (0.8)		
How many hours you spent in homework after class every day, n (%)						**0.000**	**0.001**
< 1 h	267 (9.2)	86 (12.5)	181 (8.1)	38 (14.7)	229 (8.6)		
1 h ~ 2 h	794 (27.3)	227 (32.9)	567 (25.5)	84 (32.6)	710 (26.8)		

Table 2 (continued)

Characteristic	Total (*n* = 2,910)	Diagnosed as URE (*n* = 689)	Diagnosed as non-URE (*n* = 2,221)	Diagnosed as URE according to criterion 2 (*n* = 258)	Diagnosed as non-URE according to criterion 2 (*n* = 2,652)	*P*-value[a]	*P*-value[b]
2 h ~ 3 h	732 (25.2)	156 (22.6)	576 (25.9)	56 (21.7)	676 (25.5)		
3 h ~ 4 h	578 (19.9)	118 (17.1)	460 (20.7)	41 (15.9)	537 (20.2)		
> 4 h	539	102 (14.8)	437 (19.7)	39 (15.1)	500 (18.9)		
Average time spent using mobile phone or iPad every day, n (%)						**0.006**	**0.000**
< 0.5 h	621 (21.3)	126 (18.3)	495 (22.3)	42 (16.3)	579 (21.8)		
0.5 ~ 1 h	606 (20.8)	125 (18.1)	481 (21.7)	35 (13.6)	571 (21.5)		
1 ~ 1.5 h	625 (21.5)	150 (21.8)	475 (21.4)	59 (22.9)	566 (21.3)		
1.5 ~ 2 h	506 (17.4)	136 (19.7)	370 (16.7)	60 (23.3)	446 (16.8)		
> 2 h	552 (19.0)	152 (22.1)	400 (18.0)	62 (24.0)	490 (18.5)		
Average TV time per week, n (%)						**0.084**	**0.232**
< 1 h	2,014 (69.2)	453 (65.7)	1,561 (70.3)	164 (63.6)	1,850 (69.8)		
1 ~ 2 h	485 (16.7)	135 (19.6)	350 (15.8)	51 (19.8)	434 (16.4)		
2 ~ 3 h	222 (7.6)	56 (8.1)	166 (7.5)	22 (8.5)	200 (7.5)		
3 ~ 4 h	89 (3.1)	25 (3.6)	64 (2.9)	12 (4.7)	77 (2.9)		
> 4 h	100 (3.4)	20 (2.9)	80 (3.6)	9 (3.5)	91 (3.4)		
Daily outdoor activity (during daylight hours), n (%)						**0.012**	**0.009**
< 0.5 h	955 (32.8)	196 (28.4)	759 (34.2)	64 (24.8)	891 (33.6)		
0.5 h ~ 1 h	1,194 (41.0)	287 (41.7)	907 (40.8)	108 (41.9)	1,086 (41.0)		
1 h ~ 2 h	449 (15.4)	129 (18.7)	320 (14.4)	50 (19.4)	399 (15.0)		
2–3 h	167 (5.7)	45 (6.5)	122 (5.5)	23 (8.9)	144 (5.4)		
> 3 h	145 (5.0)	32 (4.6)	113 (5.1)	13 (5.0)	132 (5.0)		
How long do you rest after close work (Rest mode such as looking out, outdoor activities, closing eyes), n (%)						**0.082**	**0.081**
< 0.5 h	795 (27.3)	200 (29.0)	595 (26.8)	74 (28.7)	721 (27.2)		
0.5 h ~ 1 h	932 (32.0)	241 (35.0)	691 (31.1)	99 (38.4)	833 (31.4)		
1 h ~ 2 h	628 (21.6)	133 (19.3)	495 (22.3)	45 (17.4)	583 (22.0)		
2 h ~ 3 h	220 (7.6)	45 (6.5)	175 (7.9)	18 (7.0)	202 (7.6)		
> 3 h	335 (11.5)	70 (10.2)	265 (11.9)	22 (8.5)	313 (11.8)		
Normal reading distance, n (%)						**0.623**	**0.528**
> 33 cm	1,408 (48.4)	339 (49.2)	1,069 (48.1)	120 (46.5)	1,288 (48.6)		
< 33 cm	1,502 (51.6)	350 (50.8)	1,152 (51.9)	138 (53.5)	1,364 (51.4)		
Which row is sitting in the classroom, n (%)						**0.040**	**0.020**
1	487 (16.7)	105 (15.2)	382 (17.2)	52 (20.2)	435 (16.4)		
2	467 (16.0)	104 (15.1)	363 (16.3)	55 (21.3)	412 (15.5)		
3	492 (16.9)	115 (16.7)	377 (17.0)	49 (19.0)	443 (16.7)		
4	479 (16.5)	113 (16.4)	366 (16.5)	38 (14.7)	441 (16.6)		
5	409 (14.1)	112 (16.3)	297 (13.4)	27 (10.5)	382 (14.4)		
6	357 (12.3)	81 (11.8)	276 (12.4)	23 (8.9)	334 (12.6)		
More backward	219 (7.5)	59 (8.6)	160 (7.2)	14 (5.4)	205 (7.7)		
How many times do you undergo visual examinations at school per year, n (%)						**0.294**	**0.925**
1	177 (6.1)	38 (5.5)	139 (6.3)	15 (5.8)	162 (6.1)		
2	1,410 (48.5)	341 (49.5)	1,069 (48.1)	119 (46.1)	1,291 (48.7)		
3	1,130 (38.8)	258 (37.4)	872 (39.3)	107 (41.5)	1,023 (38.6)		
4	144 (4.9)	43 (6.2)	101 (4.5)	13 (5.0)	131 (4.9)		
More times	49 (1.7)	9 (1.3)	40 (1.8)	4 (1.6)	45 (1.7)		
Parents' myopia, n (%)						**0.349**	**0.158**
Neither	1,157 (39.8)	317 (46.0)	840 (37.8)	116 (45.0)	1,041 (39.3)		
One of them	1,075 (36.9)	233 (33.8)	842 (37.9)	83 (32.2)	992 (37.4)		
Both	678 (23.3)	139 (20.2)	539 (24.3)	59 (22.9)	619 (23.3)		
Age (years)	15.23 ± 1.77	14.99 ± 1.84	15.30 ± 1.75	15.23 ± 1.86	15.23 ± 1.77	0.000	0.101

Table 2 (continued)

Characteristic	Total (*n* = 2,910)	Diagnosed as URE (*n* = 689)	Diagnosed as non-URE (*n* = 2,221)	Diagnosed as URE according to criterion 2 (*n* = 258)	Diagnosed as non-URE according to criterion 2 (*n* = 2,652)	*P*-value[a]	*P*-value[b]
Height (cm)	166.82 ± 10.31	168.70 ± 8.46	166.24 ± 10.76	164.70 ± 8.04	167.03 ± 10.48	0.002	0.040
Weight (kg)	59.28 ± 12.92	62.36 ± 12.37	58.32 ± 12.94	57.64 ± 13.42	59.44 ± 12.86	0.110	0.222

[a]Comparisons between UREs and other parameters

[b]Comparisons between UREs according to criterion 2 and other parameters

Abbreviation: URE: uncorrected refractive error

social and economic impacts, such as limiting educational and employment opportunities of economically active persons, healthy individuals, and communities [7]. For individuals, past studies reported that URE and VI can exacerbate anxiety [27], reading difficulties [28], and antisocial behavior [29], and impact the quality of life [30] and harm self-esteem [31]. Intervention in URE is one of the most simple, effective, and cost-effective methods to improve the burden of vision loss [32]. Pirindhavellie et al. [33] found that spectacle correction improves children dividuals limiting educational and employment opportunities, mental health, and quality of life. Pirindhavellie et al. [33] found that spectacle correction improves children's cognitive and educational well-being, psychological well-being, mental health, and quality of life.

URE is prevalent in economically disadvantaged countries and regions as well as developed countries [12]. However, as these ratios depend on the definition of URE, research populations, examination methods, publication times, and socio-economic issues, direct comparisons cannot be made. Most previous studies on URE have used the definition of Bourne et al. [34]. According to this definition, URE is present when the presenting vision of the better eye is worse than 6/12 but becomes more than 6/12 after correction, as described in URE2 in this study. The reason for choosing the cut-off point of 6/12 instead of 6/18 is because it may better represent the visual needs of modern life, so this has also become the current trend [35]. Table 4 lists recent epidemiological studies on the prevalence of URE in children and adolescents, which shows that the visual threshold of 6/12 is also accepted by increasing studies [24, 36–43]. We also note that in recent years, an increasing number of studies have adopted VI in either eye [24, 36, 38, 39, 42] rather than in better eyes [37, 40, 41, 43] as the diagnostic criteria. Based on the results of studies using either eye as the standard, the prevalence of URE is generally higher than in studies using better eyes as the standard. Previous studies have shown that unilateral VI has an impact on visual function and health-related quality of life in different environments [44]. Especially for children and adolescents, an imbalance in visual signal input from both eyes can lead to myopia progression, stereoscopic vision dysfunction, and affect the sharpness of adult stereoscopic vision [45]. In the current study, the prevalence of URE was 23%, and the prevalence of URE2 was 8%, indicating that using data from both eyes for the definition of URE provided a more complete range of VI in the adolescent population.

One of the most important findings of this study was the relationship between anisometropia and URE, which has not been mentioned in previous studies. Anisometropia can cause diplopia, aniseikonia, decreased stereopsis, visual fatigue, strabismus, amblyopia, and spectacle intolerance [46]. The results of the present study showed that anisometropia was one of the most frequent causes of URE. Adolescents with anisometropia were 1.92 times more likely to suffer from URE than adolescents without anisometropia (OR: 1.92, 95% CI: 1.59–2.31, $P<0.001$). More important, when using URE2 as a diagnostic criterion, anisometropia was a protective factor for URE2. When compared with adolescents without anisometropia, anisometropia reduced URE2 by 28% (OR: 0.72, 95% CI: 0.54–0.97, $P=0.031$). As shown in Table 1, the prevalence of anisometropia among Chinese high school adolescents reached as high as 33.0%. This high prevalence of anisometropia was quite unusual and worth noting. In previous studies, as URE2 has been widely used [12], more attention has been directed to the eye with a better PVA, leading to serious neglect of refractive issues in the other eye [36]. This suggests that in future visual intervention strategies, attention should be paid to the visual status of each eye.

In the present study, the prevalence of myopia among Chinese high school adolescents reached 96.5%. Such a high prevalence of myopia is rare, both in China and the rest of the world [47]. Consistent with expectations, myopia was the most important risk factor for URE. As shown in Table 1, from the age of 12 to 19 years, the prevalence of myopia showed an increasing trend with age (Ptrend = 0.027) and the SE of the less ametropic eye tended to decrease with age (Ptrend < 0.0001). However, after adjustments for other characteristics, age showed a protective factor for URE (aOR: 0.87, 95% CI: 0.82–0.93, $P<0.001$). This was mainly due to the fact that more participants underwent refractive correction with age, and more participants met the requirements for refractive correction with age. As shown in Table 1, from the

Table 3 Univariate and multivariate logistic regression analysis of the uncorrected refractive error (URE) among all participants according to different URE diagnostic criteria ($n = 2,910$)

Characteristic	Univariate analysis according to URE			Multivariate analysis according to URE			Univariate analysis according to URE2			Multivariate analysis according to URE2		
	Crude OR	95% CI	*P* value	Adjusted OR	95% CI	*P* value	Crude OR	95% CI	*P* value	Adjusted OR	95% CI	*P* value
Sex												
Male	1			1			1			1		
Female	1.28	1.07–1.51	0.005	0.84	0.67–1.05	0.128	0.79	0.61–1.02	0.071	1.02	0.73–1.44	0.893
Refractive state												
Non myopia	1			1			1			1		
Low myopia	3.78	1.82–7.82	0.000	4.07	1.93–8.58	0.000	9.48	1.32–68.29	0.026	13.24	1.82–96.45	0.011
High myopia	3.92	1.86–8.28	0.000	4.45	2.06–9.61	0.000	13.73	1.88–100.07	0.010	22.57	3.04–167.29	0.002
Anisometropia, n (%)												
Yes	1.83	1.53–2.18	0.000	1.92	1.59–2.31	0.000	0.754	0.57–1.00	0.052	0.72	0.54–0.97	0.031
No	1			1			1			1		
Premature or not, n (%)												
Yes	0.95	0.69–1.31	0.75	1.10	0.78–1.54	0.588	1.09	0.68–1.75	0.712	1.16	0.72–1.90	0.541
No	1			1			1			1		
Feeding status in childhood, n (%)												
Breast feeding	1			1			1			1		
Mixed feeding	0.89	0.73–1.10	0.29	0.94	0.75–1.17	0.571	0.88	0.65–1.20	0.432	1.02	0.74–1.41	0.918
Formula feeding	0.91	0.67–1.23	0.53	0.92	0.66–1.27	0.603	1.09	0.70–1.69	0.711	1.22	0.77–1.94	0.390
Other types of infant feeding	1.34	0.78–2.30	0.29	1.45	0.82–2.59	0.206	1.11	0.49–2.53	0.808	1.23	0.52–2.90	0.635
Preference for sweet foods, n (%)												
Yes	1.01	0.83–1.21	0.942	0.93	0.75–1.14	0.475	0.84	0.64–1.11	0.227	0.071	0.56–1.02	0.76
No	1			1			1			1		
Preference for carbonated drinks												
Yes	1.15	0.96–1.36	0.125	1.15	0.96–1.39	0.14	1.16	0.89–1.51	0.263	1.13	0.85–1.50	0.393
No	1			1			1			1		
You often hear parents' reminders about your poor daily sitting posture (approximately every month)												
Yes	1.09	0.86–1.39	0.480	0.96	0.72–1.28	0.779	1.13	0.78–1.63	0.512	0.95	0.62–1.47	0.822
No	1			1			1			1		
You often hear teachers' reminders about your poor daily sitting posture (approximately every month)												
Yes	1.23	1.01–1.50	0.044	1.18	0.92–1.49	0.188	1.29	0.95–1.75	0.110	1.13	0.79–1.62	0.513
No	1			1			1			1		
Where to stay during class interval												
Classroom	1.03	0.86–1.24	0.750	1.02	0.83–1.25	0.86	1.16	0.87–1.54	0.319	1.14	0.83–1.55	0.419
Outdoors	1			1			1			1		
When you notice a decrease in your eyesight, you will inform your parents												
Yes	0.83	0.65–1.06	0.136	0.85	0.65–1.12	0.258	0.79	0.56–1.12	0.179	0.75	0.50–1.10	0.14
No	1			1			1					

Table 3 (continued)

Characteristic	Univariate analysis according to URE			Multivariate analysis according to URE			Univariate analysis according to URE2			Multivariate analysis according to URE2		
	Crude OR	95% CI	*P* value	Adjusted OR	95% CI	*P* value	Crude OR	95% CI	*P* value	Adjusted OR	95% CI	*P* value
If your parents realize that your eyesight has decreased, they will timely take you to medical institution for examination												
Yes	0.67	0.54–0.83	0.000	0.69	0.55–0.88	0.003	0.86	0.63–1.19	0.370	0.95	0.66–1.36	0.764
No	1			1			1			1		
Daily sleep time												
< 6 h	1			1			1			1		
6 ~ 7 h	1.37	1.08–1.74	0.010	1.17	0.90–1.52	0.241	1.55	1.05–2.29	0.027	1.27	0.84–1.93	0.256
7 ~ 8 h	1.50	1.15–1.97	0.003	1.12	0.82–1.52	0.488	1.85	1.21–2.83	0.005	1.31	0.82–2.10	0.257
8 ~ 9 h	1.59	1.05–2.42	0.030	1.05	0.66–1.66	0.848	2.05	1.11–3.79	0.021	1.38	0.71–2.68	0.341
> 9 h	2.89	1.26–6.61	0.012	2.12	0.89–5.04	0.091	3.99	1.41–11.27	0.009	3.29	1.10–9.83	0.033
How many hours you spent in homework after class every day												
< 1 h	1			1			1			1		
1 ~ 2 h	0.84	0.63–1.14	0.262	0.77	0.55–1.06	0.118	0.71	0.47–1.08	0.107	0.70	0.45–1.09	0.111
2 ~ 3 h	0.57	0.42–0.78	0.000	0.52	0.36–0.72	0.000	0.50	0.32–0.77	0.002	0.51	0.32–0.82	0.006
3 ~ 4 h	0.54	0.39–0.75	0.000	0.55	0.39–0.79	0.001	0.46	0.29–0.73	0.001	0.51	0.31–0.85	0.010
> 4 h	0.49	0.35–0.69	0.000	0.55	0.38–0.79	0.001	0.47	0.29–0.76	0.002	0.62	0.37–1.04	0.071
Average time spent using mobile phone or iPad every day												
< 0.5 h	1			1			1			1		
0.5 ~ 1 h	1.02	0.77–1.35	0.884	1.02	0.77–1.37	0.872	0.85	0.53–1.34	0.476	0.81	0.50–1.31	0.396
1 ~ 1.5 h	1.24	0.95–1.62	0.115	1.29	0.97–1.71	0.085	1.44	0.95–2.17	0.085	1.35	0.87–2.07	0.179
1.5 ~ 2 h	1.44	1.09–1.91	0.009	1.38	1.02–1.87	0.035	1.86	1.23–2.80	0.003	1.58	1.01–2.48	0.044
> 2 h	1.49	1.14–1.96	0.004	1.52	1.12–2.07	0.008	1.74	1.16–2.63	0.008	1.38	0.87–2.19	0.176
Average TV time per week												
< 1 h	1			1			1			1		
1 ~ 2 h	1.33	1.06–1.66	0.013	1.22	0.96–1.55	0.098	1.33	0.95–1.85	0.095	1.20	0.84–1.70	0.315
2 ~ 3 h	1.16	0.84–1.60	0.357	0.97	0.70–1.36	0.856	1.24	0.78–1.98	0.366	1.04	0.63–1.70	0.877
3 ~ 4 h	1.35	0.84–2.16	0.219	1.25	0.76–2.07	0.377	1.76	0.94–3.30	0.079	1.24	0.64–2.42	0.525
> 4 h	0.86	0.52–1.42	0.560	0.65	0.38–1.12	0.120	1.17	0.55–2.25	0.760	0.69	0.33–1.45	0.331
Daily outdoor activity (during daylight hours)												
< 0.5 h	1			1			1			1		
0.5 ~ 1 h	1.23	1.00–1.51	0.053	1.14	0.91–1.42	0.230	1.38	1.00–1.91	0.047	1.24	0.88–1.73	0.216
1 ~ 2 h	1.56	1.21–2.02	0.001	1.44	1.09–1.93	0.011	1.75	1.18–2.57	0.005	1.55	1.02–2.36	0.040
2–3 h	1.43	0.98–2.08	0.063	1.36	0.92–2.09	0.136	2.22	1.34–3.70	0.002	2.13	1.24–3.66	0.006
> 3 h	1.10	0.72–1.67	0.669	0.91	0.60–1.49	0.674	1.37	0.74–2.56	0.321	1.08	0.56–2.10	0.823
How long do you rest after close work (Rest mode such as looking out, outdoor activities, closing eyes)												
< 0.5 h	1			1			1			1		
0.5 ~ 1 h	1.04	0.84–1.29	0.739	1.05	0.83–1.33	0.672	1.16	0.84–1.59	0.365	1.14	0.81–1.59	0.448
1 ~ 2 h	0.80	0.62–1.03	0.079	0.79	0.61–1.03	0.085	0.75	0.51–1.11	0.148	0.70	0.46–1.05	0.081

Table 3 (continued)

Characteristic	Univariate analysis according to URE			Multivariate analysis according to URE			Univariate analysis according to URE2			Multivariate analysis according to URE2		
	Crude OR	95% CI	*P* value	Adjusted OR	95% CI	*P* value	Crude OR	95% CI	*P* value	Adjusted OR	95% CI	*P* value
2 ~ 3 h	0.77	0.53–1.10	0.150	0.81	0.55–1.19	0.279	0.87	0.51–1.49	0.607	0.83	0.48–1.46	0.520
> 3 h	0.79	0.58–1.07	0.125	0.91	0.65–1.26	0.557	0.69	0.42–1.12	0.133	0.73	0.43–1.22	0.226
Normal reading distance												
< 33 cm	0.958	0.81–1.14	0.623	0.97	0.81–1.17	0.755	1.09	0.84–1.40	0.528	1.11	0.85–1.46	0.443
> 33 cm	1			1			1			1		
Which row is sitting in the classroom												
1	1			1			1			1		
2	0.95	0.71–1.27	0.723	0.88	0.65–1.20	0.426	1.12	0.75–1.67	0.591	1.05	0.69–1.60	0.813
3	1.02	0.77–1.35	0.904	0.97	0.72–1.31	0.848	0.93	0.61–1.40	0.712	0.92	0.59–1.41	0.688
4	0.75	0.56–1.01	0.059	0.75	0.54–1.03	0.075	0.72	0.47–1.12	0.144	0.78	0.49–1.24	0.288
5	0.83	0.61–1.12	0.227	0.84	0.60–1.17	0.303	0.59	0.36–0.96	0.034	0.63	0.37–1.05	0.076
6	0.63	0.45–0.88	0.007	0.65	0.45–0.94	0.023	0.58	0.35–0.96	0.034	0.66	0.38–1.14	0.136
More backward	0.76	0.52–1.12	0.154	0.83	0.54–1.25	0.365	0.57	0.31–1.06	0.073	0.69	0.36–1.33	0.269
How many times do you undergo visual examinations at school per year												
1	1			1			1			1		
2	1.17	0.80–1.70	0.425	1.22	0.82–1.81	0.331	1.00	0.57–1.75	0.987	1.07	0.60–1.92	0.819
3	1.08	0.74–1.59	0.687	1.00	0.67–1.51	0.983	1.13	0.64–1.99	0.673	1.15	0.63–2.09	0.645
4	1.56	0.94–2.58	0.086	1.34	0.78–2.31	0.286	1.07	0.49–2.33	0.861	1.22	0.53–2.78	0.640
More times	0.82	0.37–1.85	0.636	0.59	0.25–1.39	0.231	0.96	0.30–3.04	0.945	0.88	0.27–2.89	0.829
Parents' myopia												
Neither	1			1			1			1		
One of them	0.87	0.71–1.05	0.153	0.85	0.69–1.05	0.123	0.75	0.56–1.01	0.057	0.81	0.60–1.11	0.191
Both	0.96	0.77–1.20	0.713	0.94	0.74–1.19	0.613	0.86	0.62–1.19	0.352	0.94	0.66–1.33	0.723
Age (years)												
	0.91	0.86–0.95	0.000	0.87	0.82–0.93	0.000	1.00	0.93–1.07	0.989	0.99	0.91–1.08	0.793
Height (cm)												
	0.98	0.97–0.99	0.000	0.99	0.98–1.01	0.293	0.97	0.96–0.99	0.000	0.98	0.96–1.00	0.051
Weight (kg)												
	0.99	0.98–1.00	0.002	1.00	0.99–1.01	0.875	0.99	0.98–1.00	0.033	1.00	0.99–1.01	0.981

Abbreviation: URE: uncorrected refractive error; OR: odds ratio; 95% CI: 95% confidence interval

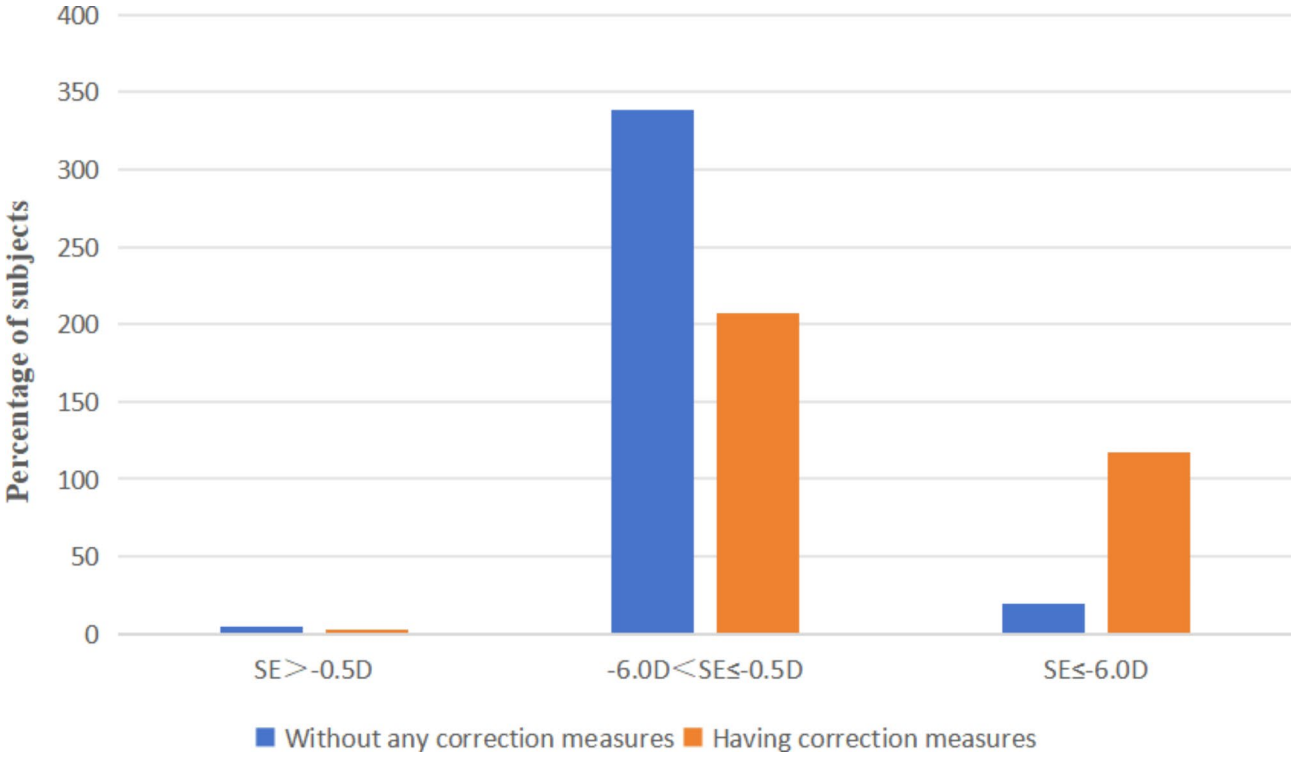


Fig. 2 The status of adolescents with or without refractive correction in the population of uncorrected refractive errors sorted by refractive status. Abbreviation: SE: spherical equivalent

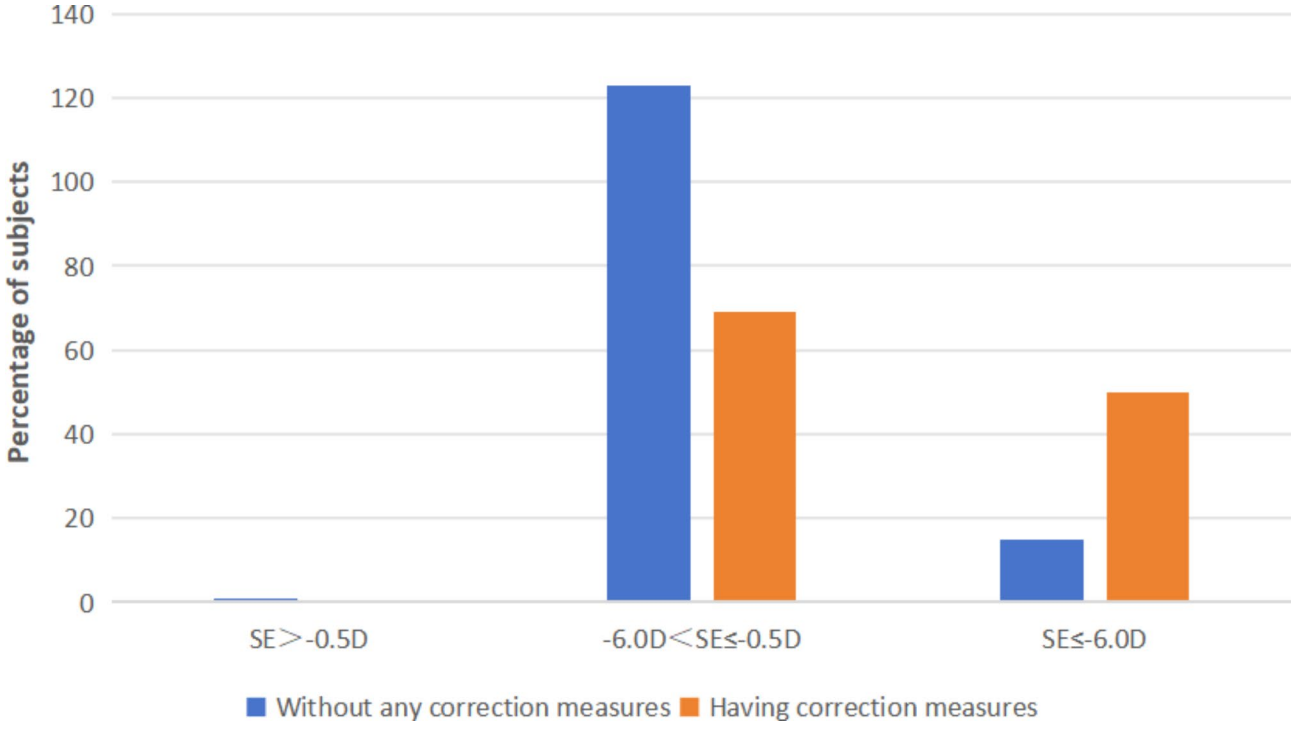


Fig. 3 The status of adolescents with or without refractive correction in the uncorrected refractive error population according to diagnostic criteria 2. Abbreviation: SE: spherical equivalent

Table 4 Epidemiological studies on the recent prevalence of uncorrected refractive error in children and adolescents

Study (year)	Number of participants	Study population and country	Age range (or mean ± SD)	Prevalence of URE	Visual acuity boundary in diagnostic criteria (Snellen)	A better eye or either eye is used in diagnostic criteria
Bakare et al. (2022) [36]	*n* = 3,054	From municipal schools in the suburbs of the Pimpri Chinchwad Municipal Corporation area; India	5–18 years	12.04%	For age group of 5–6 years: 6/15; For children older than seven years: 6/12	Either eye
Kodjebacheva et al. (2011) [38]	*n* = 11,332	First-grade students from three school districts in Southern California; USA	5–7 years	7.60%	6/12	Either eye
Mayro et al. (2018) [42]	*n* = 18,974	From elementary schools in low-income areas of Philadelphia; USA	5–12 years	13.10%	grades K-1: 20/40 grades 2–5: 20/30	Either eye
Alrahili et al. (2017) [39]	*n* = 1,893	From 8 kindergarten and eight primary schools in Medina; Saudi Arabia	3–10 years	34.90%	3–5 years: 6/12; 5–10 years: 20/32	Either eye
Wang et al. (2015) [24]	*n* = 4,376	Urban Migrant Children in Eastern China; China	Mean (10.0 ± 0.81) years	27.50%	6/12	Either eye
He et al. (2014) [40]	*n* = 9,512	children of migrant workers in Shanghai; China	7–12 years	11.26%,	6/12	Better eye
Cui et al. (2021) [41]	*n* = 1,856	From school-age children in Lhasa; China	6–11 years	11.70%	6/12	Better eye
Bright et al. (2018) [37]	*n* = 1,664	From a national survey conducted of people aged 7 and over; Rwanda	7–16 years	0.38%	6/12	Better eye
Brandt et al. (2021) [42]	*n* = 1,874	From school-age children in the city of Leipzig and surrounding areas; German	3–16 years	0.50%	6/18	Better eye

age of 12 to 19 years, the prevalence of REC and eREC showed an increasing trend with age (Ptrend=0.018 and Ptrend=0.019, respectively). The eREC was an important indicator for refractive error services. There is insufficient data on children and adolescents with eREC [48]. Our data showed that the prevalence of eREC and REC among Chinese adolescents aged 12 to 19 years were 71.7% and 85.1%, respectively. Compared with previous data [48], these results reflected the high proportion of Chinese teenagers who underwent refractive correction and met their refractive correction needs. However, it is worth noting that among adolescents with URE, 52.5% of adolescents did not undergo any refractive correction. Possible explanations for this finding may be that knowledge or accessibility was insufficient. Some parents realize that their children have poor eyesight, but they do not want their children to wear glasses. Some parents think that glasses are too expensive, while some parents do not know how to obtain glasses [47]. In addition, among adolescents with URE, 47.5% underwent refractive corrections. However, it was possible that the prescription for spectacles was incorrect, and more commonly, after the progression of myopia, the original prescription for glasses did not match the current refractive state. These needs may require policy managers to emphasize the diagnosis and intervention of refractive errors in adolescents, and to eliminate common misunderstandings of parents about vision care [49].

A school-based screening program provides a means for examining all adolescents. In the present study, all high school adolescents received at least one visual examination per year, with 48.5% and 38.8% receiving two and three visual examinations, respectively, per year. However, in the context of frequent visual examinations, simply increasing the frequency of visual examinations did not have an effect on the prevalence of URE ($P>0.05$). Correspondingly, when a parent realizes that their child's vision has decreased, promptly taking their child to a medical institution for examination reduced the prevalence of URE by 31% (OR: 0.69, 95% CI: 0.55–0.88, $P=0.003$). However, the visual screening conducted by schools is often not as comprehensive as the assessment conducted by medical professionals, and there may be problems in the transition from school-based examinations to medical institution examinations.

Another important finding of the current study was that despite being a close-range activity, homework was a protective factor for URE, while use of electronic products was a risk factor for URE. Various studies reported that environmental factors played an important role in the development of refractive error [50]. Although more homework and electronic device use have been proven to be associated with an increase in the prevalence of myopia, parents and adolescents may not attach the same importance and handle these two situations in the same way. Chinese teenagers face high academic pressure [51]. When faced with more homework and unable to see clearly, teenagers often wear glasses as wearing spectacles was the most important protective factor for URE [52].

Limitations

There were several limitations in this study. It was a cross-sectional study, so it did not follow the evolution of participants over time. Continuous follow-up studies on children and adolescents are therefore needed to assess the evolution of URE over time. Second, racial differences in the correction of refractive errors [11] and these associations from a Han-dominated population may not be generalizable to other ethnic groups. In addition to refractive error, a detailed eye examination was not conducted for each participant, to more specifically determine the causes of vision impairments. Finally, further studies are needed to elucidate the potential causes of URE. In addition to the factors included in the current study, it may also be necessary to include factors such as living environment, socioeconomic status, academic pressure, access to health insurance, race, broader educational stages, and awareness of eye care needs.

Conclusions

In conclusion, this study showed a high prevalence of URE among Chinese adolescents. Myopia stands as the foremost risk factor for URE. The impacts of anisometropia and increased daily use of electronic devices on URE were significant. Timely visual examinations by medical institutions could serve as an effective protective factor against URE. Public health interventions should prioritize raising awareness of URE, especially for children and adolescents. Further research on adjusting intervention strategies is therefore needed to eliminate preventable visual impairments.

Abbreviations

BCVA	Best-corrected visual acuity
CI	Confidence interval
LS	Lifestyle
OR	Odds ratio
PVA	Presenting visual acuity
SE	Spherical equivalent
URE	Uncorrected refractive error
VA	Visual acuity
VI	Visual impairment

Supplementary Information

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Supplementary Material 1

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Author contributions

Lu P, Sun Z and Song Y conceived the study. Zhou Y, Huang X, Zhu Y and Cai Q designed the study. Chen X and Li L collected the data. Zhou Y and Chen X analyzed the data and prepared the article. All authors reviewed the article and approved the final version. All authors had full access to all the data in the study and accept responsibility to submit for publication.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding authors on reasonable request.

Declarations

Ethics approval and consent to participate

The protocol and consent procedures were approved by the ethics committee of the Second Affiliated Hospital of Nantong University, China (approval number: 2020KT068). All protocols used in this study followed the tenets of the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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