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*Research Article*

# Age-Related Change of Axial Length, Spherical Equivalent, and Prevalence of Myopia and High Myopia in School-Age Children in Shanghai: 2014–2018

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*Purpose*. To investigate the age-related change of axial length (AL), spherical equivalent (SE), and prevalence of myopia and high myopia in children at 7–18-year-olds in Shanghai in 2014 and 2018, respectively. *Methods*. This was an observational study in Shanghai. The same 3 schools were selected in 2014 and 2018, respectively. AL, SE, prevalence of myopia and high myopia, height, and weight were measured. A questionnaire regarding the lifestyles was completed. *Results*. Mean age was smaller in 2018 than in 2014 ($P < 0.001$), and mean AL was shorter in 2018 than in 2014 ($P = 0.003$), whereas mean SE was greater in 2018 than in 2014 ($P < 0.001$). The prevalence of myopia and high myopia was lower in 2018 than in 2014 ($P < 0.001$ and $P = 0.013$, respectively). Mean AL increased with age from 7-year-olds to 18-year-olds in 2014 and 2018 (both $P < 0.001$), respectively. Mean SE decreased with age in 2014 and 2018 (both $P < 0.001$), respectively. The prevalence of myopia and high myopia increased with age in 2014 and 2018 (all $P < 0.001$), respectively. Less mean time outdoors and more mean time of study of all children were observed in 2018 than in 2014 ($P = 0.018$ and $P < 0.001$, respectively). *Conclusion*. This study shows normative growth values for AL and SE in Shanghai children at the age of 7–18-year-olds, as well as the age-specific prevalence of myopia and high myopia.

## 1. Introduction

Myopia is the most common eye disorder worldwide [1–3], which is mainly caused by a mismatch between the optical power of the eye and its excessively long axial length (AL). The correction modalities for myopia include spectacle lenses [4], contact lenses [5], photorefractive keratectomy [6], laser epithelial keratomileusis [7], laser in situ keratomileusis (LASIK) [7], femtosecond laser-assisted LASIK [8], small-incision lenticule extraction (SMILE) [8], and Visian implantable collamer lens (ICL) implantations [9]. However, due to the excessive axial elongation, high myopia can increase the risk of visual impairment complications (e.g., retinal detachment, maculopathy, and glaucoma) [1, 10, 11], which can lower life satisfaction and reduce the quality of life [12, 13]. Thus, the control of myopia progression has become very essential.

Although the mechanism of myopia development is still unclear, myopia is the result of genetic and environmental factors. The prevalence of myopia and high myopia is relatively high in East and Southeast Asian regions [14–17], partly due to increasing environment risk factors. The changing lifestyles (e.g., time outdoors and time of study) [17, 18] and classical risk factors (e.g., education [19, 20] and ethnicity [3]) are associated with the increased risk of progression of myopia in school-age children. Updating the age-related change trends of myopia-related data in childhood is very important for myopia prevention and controlling. We conducted this study to investigate age-related change trends for AL, SE, and prevalence of myopia and high myopia in children at 7–18-year-olds in Shanghai in 2014 and 2018, respectively. In addition, we also investigated whether these differences between 2014 and 2018 could be explained by the time outdoors and time of study.

## 2. Methods

*2.1. Subjects.* This was an observational study in Jinshan District, Shanghai, China. One primary school, one junior high school, and one senior high school were randomly selected in 2014, and the same schools were studied in 2018. The exclusion criteria were a history of severe systemic and ocular diseases (e.g., cataract, glaucoma), topical application of low-concentration atropine eye drops, and orthokeratology lens correction. The study children were divided to three groups: primary school group (7–11-year-olds), junior high school group (12–15-year-olds), and senior high school group (16–18-year-olds).

The study was approved by the Ethics Committee of Jinshan Hospital of Fudan University, China. All study procedures adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from the parents or guardians of all children.

*2.2. Examination.* The children's ocular examinations were completed from October 1 to December 31 in 2014 and from September 1 to October 31 in 2018, respectively. Axial length (AL) was obtained using an ocular biometry system (IOL Master; Carl Zeiss Meditec, Oberkochen, Germany). According to our previous studies [21, 22], refraction was measured using an autorefractor (RK-F1; Canon Corporation, Tokyo, Japan) without cycloplegia. Body height and weight were recorded for all children. The height and weight were measured in a standard manner without shoes and thick clothes.

Furthermore, a questionnaire regarding the daily lifestyles was completed by the child's parents or guardians when the child started school in September. Time outdoors and time of study were obtained using questions such as "How much time does your child spend outdoors every day?" and "How much time does your child spend in study every day?" separately for weekdays and weekend days, respectively. The mean number of hours per day was calculated as time spent during weekdays $\times 5 +$ time spent in weekend days $\times 2/7$.

*2.3. Statistical Analysis.* Both eyes of each child were examined, and only data from the right eye was used for analysis. Spherical equivalent (SE) was calculated as the sum of sphere power and half of cylinder power. Myopia was defined as SE $\leq -0.50$ *D* and high myopia as SE $\leq -6.00$ *D* [23]. Furthermore, high myopia was also analyzed using the definition of AL > 26 mm [24].

SPSS V.17.0 software was used for data analysis. The independent *t*-test was used to compare the differences of age, AL, and SE between 2014 and 2018. One-way analysis of variance with the Bonferroni post hoc test was used to analyze the differences of age, AL, and SE in 2014 and 2018, respectively. The chi-square test was used to analyze the differences of prevalence of myopia and high myopia in 2014 and 2018, respectively, and to compare the differences between 2014 and 2018. All *P* values were two-sided and considered statistically significant when less than 0.05.

## 3. Results

The characteristics for each age group in 2014 and 2018 are shown in Table 1. A total of 3057 children were examined in 2014 and 3658 children in 2018. Among them, there were 1478 (48.3%) and 1817 (49.7%) girls in 2014 and 2018, respectively. The numbers of girls in 2014 and 2018 were smaller than of boys in primary school and junior high school, whereas the numbers of girls in 2014 and 2018 was greater than the number of boys in senior high school.

The comparisons of age, AL, and SE of children between 2018 and 2014 are shown in Table 2. Mean age of all the children was smaller in 2018 than in 2014 ($P < 0.001$). Children of primary school, junior high school, and senior high school were younger in 2018 than in 2014 ($P < 0.001$, $P < 0.001$, and $P = 0.049$, respectively). Mean AL of all children was shorter in 2018 than in 2014 ($P = 0.003$). However, no significant differences were found in children of primary school, junior high school, and senior high school between 2018 and 2014 (all $P > 0.05$). Further analysis showed that boys had shorter AL in 2018 than in 2014 ($24.17 \pm 1.34$ mm vs. $24.05 \pm 1.30$ mm, $P = 0.009$), and no significant difference was found in girls between 2018 and 2014 ($23.72 \pm 1.35$ mm vs $23.65 \pm 1.31$ mm, $P = 0.160$). In 2014, mean AL increased from $22.54 \pm 0.65$ mm at 7-year-olds to $25.05 \pm 1.26$ mm at 18-year-olds ($P < 0.001$, Figure 1(a)), and in 2018, mean AL increased from $22.64 \pm 0.72$ mm to $25.09 \pm 1.20$ mm across this same period ($P < 0.001$, Figure 1(a)). Mean ALs of 9- and-11-year-old children were longer in 2018 than in 2014 ($P = 0.001$ and $P = 0.001$, respectively). Furthermore, mean SE of all the children was less negative in 2018 than in 2014 ($P < 0.001$). However, no significant differences were found in children of primary school, junior high school, and senior high school between 2018 and 2014 (all $P > 0.05$). In 2014, mean SE decreased from $+0.09 \pm 0.78$ *D* at 7-year-olds to $-3.97 \pm 2.30$ *D* at 18-year-olds ($P < 0.001$, Figure 1(b)), and in 2018, mean SE decreased from $+0.07 \pm 0.87$ *D* to $-4.07 \pm 2.51$ *D* across this same period ($P < 0.001$, Figure 1(b)). Mean SEs of 11- and 15-year-old children were more negative in 2018 than in 2014 ($P = 0.036$ and $P = 0.003$, respectively), whereas mean SE of 17-year-old children was greater in 2018 than in 2014 ($P = 0.043$).

The comparisons of prevalence of myopia and high myopia of children between 2018 and in 2014 are also shown in Table 2. The prevalence of myopia in all the children was lower in 2018 than in 2014 ($P < 0.001$). However, the prevalence of myopia in junior high school was higher in 2018 than in 2014 ($P < 0.001$), and no significant differences between 2018 and 2014 were found in children of primary school and senior high school ($P = 0.510$ and $P = 0.519$, respectively). As illustrated in Figure 2, the prevalence of myopia increased from 17.6% at 7-year-old children to 93.3% at 18-year-olds in 2014 ($P < 0.001$) and from 15.7% to 93.6% across this same period in 2018 ($P < 0.001$). Only the prevalence of myopia of 11-year-old children was higher in 2018 than in 2014 (63.3% vs. 54.2%, $P = 0.039$). No significant difference between 2018 and 2014 was observed in the prevalence of high myopia defined by SE $\leq -6.00$ *D* in all

Table 1: Characteristics for each age group in 2014 and 2018.

| | Age (years) | 2014 | | 2018 | |
|---|---|---|---|---|---|
| | | *N* | Girls (%) | *N* | Girls (%) |
| Primary school | 7 | 250 | 132 (52.8) | 428 | 202 (47.2) |
| | 8 | 271 | 135 (49.8) | 451 | 207 (45.9) |
| | 9 | 256 | 119 (46.5) | 380 | 178 (46.8) |
| | 10 | 252 | 115 (45.6) | 275 | 136 (49.5) |
| | 11 | 247 | 110 (44.5) | 264 | 135 (51.1) |
| | Total | 1276 | 611 (47.9) | 1798 | 858 (47.7) |
| Junior high school | 12 | 233 | 114 (48.9) | 315 | 152 (48.3) |
| | 13 | 230 | 109 (47.4) | 251 | 122 (48.6) |
| | 14 | 189 | 81 (42.9) | 169 | 76 (45.0) |
| | 15 | 175 | 63 (36.0) | 149 | 62 (41.6) |
| | Total | 827 | 367 (44.4) | 884 | 412 (46.6) |
| Senior high school | 16 | 299 | 158 (52.8) | 338 | 194 (57.4) |
| | 17 | 328 | 173 (52.7) | 343 | 189 (55.1) |
| | 18 | 327 | 169 (51.7) | 295 | 164 (55.6) |
| | Total | 954 | 500 (52.4) | 976 | 547 (56.0) |

children ($P = 0.155$). However, the prevalence of high myopia in junior high school was higher in 2018 than in 2014 ($P = 0.030$), and no significant differences between 2018 and 2014 were found in children of primary school and senior high school ($P = 1.000$ and $P = 0.378$, respectively). As illustrated in Figure 3(a), the prevalence of high myopia increased from 1.6% at 11-year-olds children to 19.3% at 18-year-olds in 2014 ($P < 0.001$) and from 0.2% at 7-year-olds children to 21.4% at 18-year-olds in 2018 ($P < 0.001$). Only the prevalence of high myopia of 14-year-olds children was higher in 2018 than in 2014 (7.7% vs. 2.6%, $P = 0.029$). The prevalence of high myopia (defined by AL $>$ 26 mm) was lower in 2018 than in 2014 ($P = 0.013$). However, no significant difference was observed in the prevalence of high myopia in children of primary school, junior high school, and senior high school between 2018 and 2014 (all $P > 0.05$). As illustrated in Figure 3(b), the prevalence of high myopia increased from 1.2% at 10-year-olds children to 20.8% at 18-year-olds in 2014 ($P < 0.001$) and from 0.3% at 9-year-olds children to 21.7% at 18-year-olds in 2018 ($P < 0.001$).

The comparisons of the time outdoors and time of study of children between 2018 and 2014 are shown in Table 2 as well. Mean time outdoors of all children was less in 2018 than in 2014 ($P = 0.018$). Further analysis showed that mean time outdoors in children of primary school was less in 2018 than in 2014 ($P < 0.001$), but no significant differences between 2018 and 2014 were found in mean time outdoors in children of junior high school and senior high school ($P = 0.065$ and $P = 0.057$, respectively). Mean time of the study of all children was more in 2018 than in 2014 ($P < 0.001$). Further analysis showed that the mean time of study in children of primary school, junior high school, and senior high school was more in 2018 than in 2014 (all $P < 0.001$).

## 4. Discussion

The present study showed the increase of AL and decrease of SE, as well as the increase of prevalence of myopia and high myopia with age in children at 7–18-year-olds in Shanghai in 2014 and 2018, respectively. Furthermore, age, AL, and prevalence of myopia and high myopia were smaller in 2018 than in 2014, whereas SE was greater in 2018 than in 2014. In addition, mean time outdoors was less in 2018 than in 2014, whereas the mean time of study was more in 2018 than in 2014.

In this study, the positive trends for AL reflected the continued growth of the eye from 7–18-year-olds, with an increase of approximately 0.228 mm/year in 2014 and 0.222 mm/year in 2018, respectively. Similar trends were observed in previous studies. Xiong et al. [25] found that AL increased from an average of 22.87 mm at 7-year-olds to 25.50 mm at 18-year-olds in Shanghai, with an increase of approximately 0.239 mm/year. Lu et al. [26] found that AL increased from an average of 22.76 mm at 7-year-olds to 24.50 mm at 18-year-olds in Shandong, with an increase of approximately 0.158 mm/year. Tideman et al. [27] found that mean ALs in European children were 22.36 mm at 6-year-olds, 23.10 mm at 9-year-olds, 23.41 mm at 15-year-olds, respectively, with increase of approximately 0.117 mm/year. However, there were differences in AL and the increase rate of AL among different studies. For example, AL of 25.09 ± 1.20 mm at 18-year-olds and mean increase rate of AL 0.222 mm/year in 2018 in this study were smaller than the finding of Xiong and coworkers [25], but greater than the finding of Lu and coworkers [26]. In comparison of AL and its increase rate among these studies, the differences in the genetic and socioeconomic background should be noted, which was not taken into account in this study. Furthermore, the differences in AL may be related to AL measurement techniques (IOL Master [25–27] and immersion A-scan sonogram [27]). In addition, the increase rate of AL may be associated with age range, which was greater in this study (11-year-olds) than Tideman et al. [27] (9-year-olds).

In this study, SE was negatively associated with AL and decreased with time, with a decrease of approximately 0.37 D/year in 2014 and 0.38 D/year in 2018, respectively, which was consistent with other studies. Xiong et al. [25] found that

Table 2: Comparisons of parameters of children between 2014 and 2018.

| | All | | | Primary school | | | Junior high school | | | Senior high school | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2018 | $P$ | 2014 | 2018 | $P$ | 2014 | 2018 | $P$ | 2014 | 2018 | $P$ |
| Age (years) | 12.2 ± 3.7 | 11.4 ± 3.7 | <0.001** | 8.4 ± 1.5 | 8.1 ± 1.5 | <0.001** | 13.0 ± 1.4 | 12.7 ± 1.3 | <0.001** | 16.6 ± 1.0 | 16.5 ± 1.0 | 0.049* |
| AL (mm) | 23.95 ± 1.37 | 23.85 ± 1.33 | 0.003* | 23.11 ± 0.88 | 23.13 ± 0.89 | 0.531 | 24.01 ± 1.20 | 24.04 ± 1.17 | 0.671 | 25.03 ± 1.27 | 25.02 ± 1.23 | 0.855 |
| SE (D) | −1.84 ± 2.27 | −1.62 ± 2.31 | <0.001** | −0.41 ± 1.19 | −0.37 ± 1.21 | 0.369 | −1.71 ± 1.73 | −1.82 ± 2.12 | 0.243 | −3.92 ± 2.25 | −3.74 ± 2.40 | 0.092 |
| Myopia | 63.3% | 57.8% | <0.001** | 34.3% | 33.1% | 0.510 | 51.9% | 69.2% | <0.001** | 93.9% | 93.0% | 0.519 |
| High myopia | 6.7% | 6.1% | 0.155[a] | 0.3% | 0.4% | 1.000 | 2.7% | 4.8% | 0.030* | 19.4% | 17.7% | 0.378 |
| | 8.5% | 7.1% | 0.013[b]* | 0.3% | 0.2% | 0.725 | 5.8% | 6.3% | 0.685 | 23.2% | 20.9% | 0.510 |
| Time outdoors (hour) | 64.1 ± 49.8 | 61.3 ± 45.5 | 0.018* | 67.1 ± 40.4 | 55.7 ± 33.7 | <0.001** | 72.2 ± 63.8 | 77.7 ± 58.0 | 0.065 | 52.9 ± 45.2 | 57.0 ± 47.8 | 0.057 |
| Time of study (hour) | 157.4 ± 89.5 | 180.2 ± 111.4 | <0.001** | 110.8 ± 60.0 | 137.6 ± 61.9 | <0.001** | 135.6 ± 73.7 | 162.5 ± 88.9 | <0.001** | 238.6 ± 80.9 | 274.6 ± 140.7 | <0.001** |

AL, axial length; SE, spherical equivalent. [a]High myopia was defined as $SE \leq -6.00$ $D$; [b]high myopia was defined as AL > 26 mm. $^{*}P < 0.05$; $^{**}P < 0.001$.

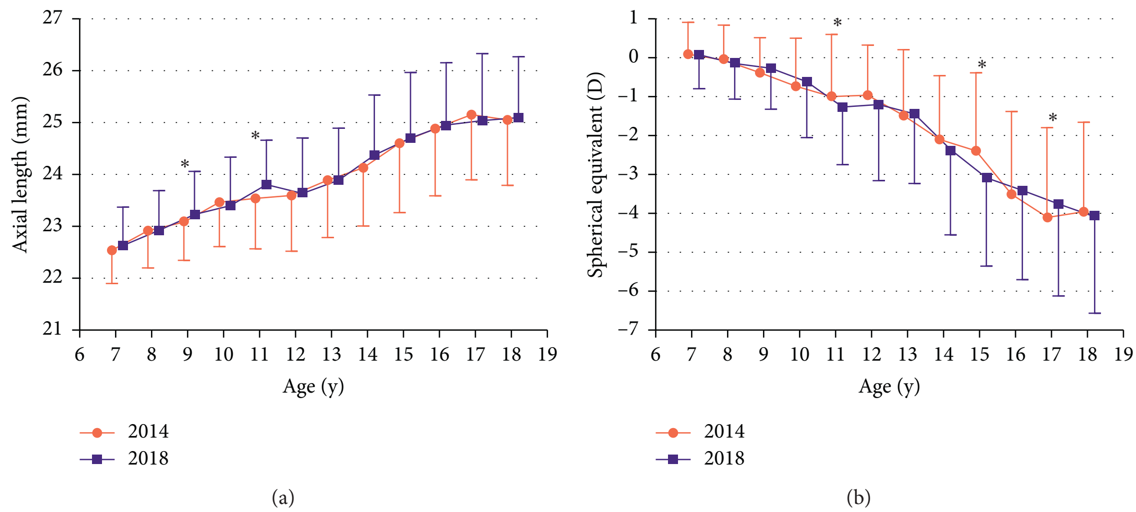


Figure 1: Trends of axial length (a) and spherical equivalent (b) in children from 7- to 18-year-olds in 2014 and 2018.

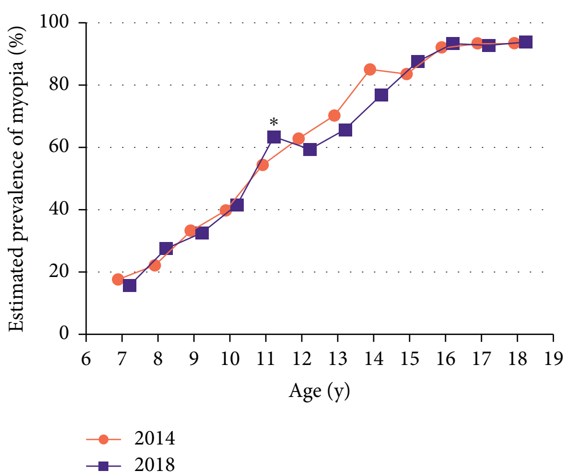


Figure 2: Trends of prevalence of myopia in children from 7- to 18-year-olds in 2014 and 2018.

SE decreased from an average of +1.05 *D* at 7-year-olds to −4.02 *D* at 18-year-olds in Shanghai, with a decrease of approximately 0.46 D/year. He et al. [28] found that SE decreased from a median of +1.25 *D* of 5-year-olds to −1.50 *D* at 15-year-olds in Guangzhou, with a decrease of approximately 0.28 D/year. Thorn et al. [29] found that SE decreased from $-0.36 \pm 1.19$ *D* in key schools and $-0.38 \pm 1.14$ *D* in nonkey schools in grade 1 (approximately 7-year-olds) to $-2.12 \pm 1.79$ *D* and $-1.41 \pm 1.56$ *D* in grade 6 (approximately 12-year-olds) in Wenzhou, with a decrease of approximately 0.35 D/year and 0.21 D/year, respectively. He et al. [30] found that mean SE was −0.17 *D* to −0.33 *D* for boys at 13–17-year-olds and −0.38 *D* to −1.25 *D* for girls in Yangjiang city, Guangdong, with a decrease of approximately 0.04 D/year and 0.22 D/year, respectively. However, the differences in SE and its decrease rate still existed among different studies. For example, the mean SE of −3.43 *D* at 15-year-olds in 2018 in this study was smaller than −2.29 *D* in Xiong and coworkers' study [25] and −1.50 *D* in He and coworkers' study [28]. Except the reasons for the differences of SE similar to AL, refraction measured with cycloplegia or not was a potential cause because of approximately 0.50 *D* in refraction after and before cycloplegia in children in our previous study [15].

In this study, the prevalence of myopia and high myopia increased with age in both 2014 and 2018, which was higher than other studies. The prevalence of myopia increased from approximately 5% at 7-year-olds to 15% at 15-year-olds in Chile [31]. The prevalence of myopia increased from 1.76% at 4-year-olds children to 84.6% at 17-year-olds in Shandong [32]. Pan et al. [33] found that the prevalence of myopia and high myopia was higher in grade 7 students (approximately 13-year-olds, 29.4% and 0.4%, respectively) compared with grade 1 students (approximately 7-year-olds, 2.4% and 0.1%, respectively). The present study showed that the prevalence of high myopia started to increase at the age of 11–13-year-olds (Figure 3). The most important predictor of high myopia in myopic children was age of myopia onset or duration of myopia progression [34]. The younger the children are at myopia onset, the more likely they are to develop into high myopia, who may suffer from sight-threatening complications. In this study, both criteria of high myopia based on SE and AL were used to obtain more comprehensive evaluation, and the higher prevalence of high myopia defined by AL was observed compared to that defined by SE.

The most interesting findings of this study were that the prevalence of myopia and high myopia decreased, as well as the decrease of AL and increase of SE in 2018 compared to 2014, which may be due to the younger children in 2018 than in 2014. These were different from other studies. The comparisons of prevalence of myopia in Taiwan children showed that it increased from 5.8% in 1983 to 21% in 2000 at 7-year-olds, 36.7% to 61% at 12-year-olds, 64.2% to 81% at 15-year-olds, and 74% to 84% at 16–18-year-olds, respectively, and the prevalence of high myopia from 10.9% to 21% at 18-year-olds [35]. In Spain, the prevalence of myopia and high myopia in children at 5–7-year-olds slightly increased from 17% in 2016 to 19% in 2017 and from 1.7% to 1.9%,

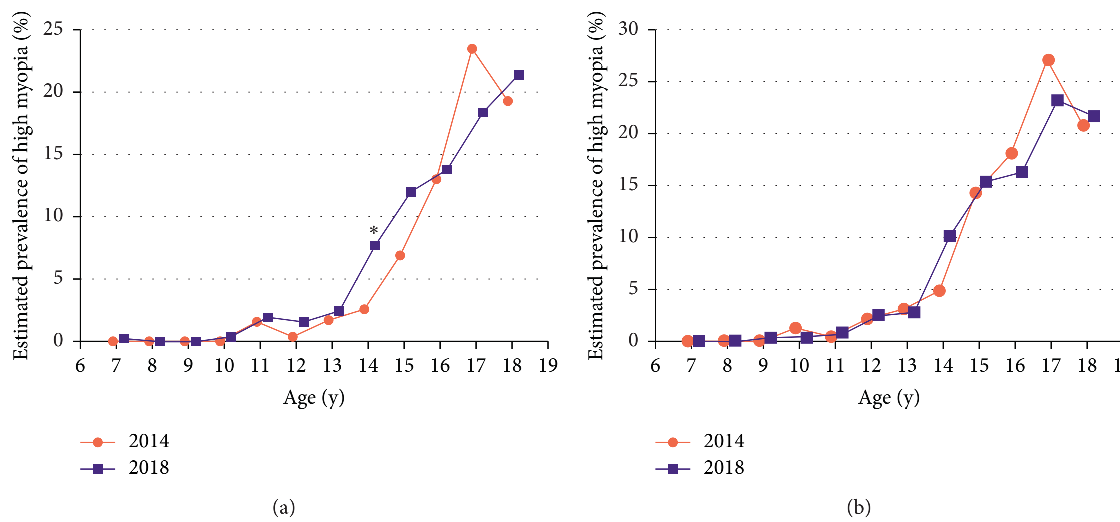


Figure 3: Trends of prevalence of high myopia defined by SE ≤ −6.00 D (a) and by AL > 26 mm (b) in children from 7- to 18-year-olds in 2014 and 2018.

respectively [36]. In the US, the prevalence of myopia increased from 12.0% in 1971-1972 to 31.2% in 1999–2004 in children at 12–17-year-olds [37]. It is predicted that the global prevalence of myopia and high myopia will increase from 23% in 2000 to 50% in 2050 and from 3% to 10% [15]. This discrepancy may be due to the improvement of myopia prevention and control concept worldwide, and the emphasis on myopia in China in recent years [38]. In addition, shorter AL in 2018 compared to 2014 could be explained by those boys who had shorter AL in 2018 compared to 2014. Prospective longitudinal studies with longer time frame are warranted to evaluate the change in AL, SE, and the prevalence of myopia and high myopia in the future.

In our study, children spent less time outdoors and more time of study in 2018 than in 2014. Previous studies have shown a protective effect of outdoor activities on myopia onset [39, 40]. Although the meta-analyses by Deng and Pang [41] suggested that the effect of time outdoors on AL and refractive error was very small, and time outdoors could retard myopic progression in all initially nonmyopic children. So, it is very critical for teachers and parents or guardians of children to emphasize the importance of outdoor activities, especially nonmyopic children.

There are several limitations in this study. First, AL was analyzed in only 3 schools with a small sample size, which could not be a representative of the whole of Shanghai. Further studies with larger sample size are warranted. Second, SE was determined by noncycloplegic autorefraction, which may lead to an overestimation of myopia. Our previous study showed that there was less than −0.50 *D* of difference between cycloplegic and noncycloplegic refraction among 7–16-year-olds children [15]. Furthermore, the procedure without cycloplegia was simple and time-saving and could not affect the later learning and writing of children.

In conclusion, the present study demonstrates normative growth values for AL and SE in Shanghai children at the age of 7–18-year-olds, as well as the age-specific prevalence of myopia and high myopia. Less time outdoors and more time of study are also observed in Shanghai children. Children should be encouraged to participate in outdoor activities, especially nonmyopia children. Longitudinal studies are needed to evaluate the trends of AL, SE, prevalence of myopia and high myopia, and associated risk factors in the future.

## Data Availability

The dataset used to support this study is available from the Dryad repository, https://doi.org/10.5061/dryad.c2fqz615c.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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