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Refractive Error in Chinese Preschool Children: The Shanghai Study

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Purpose: To examine the prevalence of refractive error and some associated factors in Chinese preschool children.

Methods: The Jinshan District Eye Study was a school-based survey of eye health in a large sample of 4- to 6-year-olds attending kindergartens from May 2013 to December 2013 in Shanghai. Refractive error was measured using an autorefractor under noncycloplegic conditions. Axial length (AL) was measured with an ocular biometry system. In addition, body height and weight were also recorded.

Results: A total of 7,166 children successfully completed their refraction measurements. The median (interquartile range) of spherical equivalent (SE) for all the children was +0.25 D (−0.13 D to +0.62 D), and the range was −15.88 to +18.13 D. The mean AL for all the children was 22.35±0.70 mm, and the range was 18.20 to 27.71 mm. The overall prevalence of myopia (−1.00 D or less), hyperopia (+2.00 D or greater), and astigmatism (1.00 D or greater) were 5.9%, 1.0%, and 12.7%, respectively. After multivariate analysis, more myopic SE (or less hyperopic SE) was significantly associated with girls, longer AL, taller, and lighter.

Conclusion: Shanghai has a high prevalence of refractive error in the world. However, longitudinal studies are needed to evaluate refractive changes over time in individual children and warranted to prevent the development of myopia.

Key Words: Refractive error—Myopia—Hyperopia—Astigmatism—Preschool children.

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Myopia is a public health problem worldwide, not only by increasingly financial burden of disease but also for the potential progression toward high myopia leading to irreversible visual impairment.[1,2] During the past several decades, the prevalence of childhood myopia has increased rapidly, and the age at onset of myopia has decreased.[3,4] It has been reported that the prevalence of myopia is more than 35% in young children in China.[5–7] Although myopia tends to stabilize at approximately 16-year-olds,[8] children with a younger age at myopia onset are prone to become highly myopic at an early stage of life and may suffer from sight-threatening complications. This condition urgently needs the vision screening and early detection of abnormality of visual development among preschool children, such as significant refractive error at an early age when visual plasticity is still high.

Although many studies have addressed the refractive error of school-aged children,[7,9–18] few population-based studies have been performed to focus on the refractive error among preschool children in China, including Shandong, Guangzhou, Xuzhou, Taiwan, and Hong Kong.[5,19–22] One of the important features of refractive error in China is that the prevalence of myopia still appears to be increasing. So, it is of importance to update recent data on the actual prevalence of refractive error. The purpose of this study was to examine the prevalence of refractive error and some associated factors in Chinese preschool children in a school-based investigation.

METHODS

Ethics Statement

The study was approved by the Ethics Committee of Shanghai Eye Disease Prevention and Treatment Center, China. All study procedures adhered to the tenets of the Declaration of Helsinki. The purpose of the study and the details regarding the examination were explained to the parents and guardians of all the children at a meeting before the examination at each school before written informed consent was obtained.

Subjects

The selection methodology has been reported in detail elsewhere.[18] Briefly, it was a preliminary study of a 3-year public health program designed to establish childhood refractive development archives in Shanghai. The program covered about one million children, including preschoolers as young as 3-year-olds and primary and secondary school students all over Shanghai. Its main objectives involved myopia prevention and control. The Jinshan District Eye Study was a school-based survey of eye health in a large sample of 4- to 6-year-olds attending kindergartens in Shanghai. All the preschool children were invited to screen for refractive error and other ocular abnormalities (e.g., amblyopia and strabismus).

Examination

The investigation was conducted in schools from May 2013 to December 2013 by 1 team with 2 optometrists, 2 public health

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TABLE 1. *Age and Sex of the Participants*

Group (yrs)	N	N (% Boys)	Age (months)
4	3,137	1,653 (52.7)	56 (53–58)
5	3,270	1756 (53.7)	66 (63–69)
6	759	404 (53.2)	73 (73–73)
All	7,166	3,813 (53.2)	62 (56–68)

physicians, and 1 ophthalmologist. An experienced public health physician specializing in the prevention of children's eye diseases from the Jinshan District Eye Disease Prevention and Treatment Center was the project coordinator and ran the whole investigation.

In all the children, body height and weight were recorded. The body height was determined in a standardized manner with the shoes being routinely removed. The subjects were asked to stand upright with the eyes looking straight ahead as much as possible. The children were asked to put off thick clothes in winter because the temperature of the examination room was set to 27°C.

The examination process began with testing visual acuity at 5 m using a standard logarithmic tumbling E chart (Yuejin Medical Optical Instruments Factory, Shanghai, China). Visual acuity was tested with and without refractive correction for those wearing spectacles. According to the previous studies,[15,16,21] refractive error was measured three times using an autorefractor (RK-F1; Canon Corporation, Tokyo, Japan) under noncycloplegic conditions because a relatively large number of parents did not accept cycloplegia. Each child was reexamined at the same visit if the differences between the any 2 results of the 3 results obtained were greater than 0.50 D. The average value of the 3 good measurements was then analyzed. Axial length (AL) was measured with an ocular biometry system (IOL Master; Carl Zeiss Meditec, Oberkochen, Germany). The measurements of AL were considered valid if individual measurements varied by no more than 0.02 mm. The average value of the five repeated measurements was then analyzed.

Data Management and Analysis

Measurements used for data analysis were obtained only from the right eye of each child. Spherical equivalent (SE) was defined as spherical power plus half-negative cylinder power. Myopia and high myopia were defined as SE of at least −1.00 and −6.00 D, respectively. Hyperopia and high hyperopia were defined as SE of at least +2.00 and +5.00 D, respectively. Astigmatism was defined as a cylindrical measurement of at least 1.00 D and was classified into three categories: with-the-rule (WTR) astigmatism (cylinder axis between 1° and 15° or 165° and 180°), against-the-rule (ATR) astigmatism (cylinder axis between 75° and 105°), and oblique astigmatism (cylinder axis between 16° and 74° or 106° and 164°). The distribution of the SE was then analyzed by stratifying the study children by 3 age groups: 4-year-olds group, 5-year-olds group, and 6-year-olds group.

All data were analyzed using SPSS version 17.0 software (SPSS Inc., Chicago, IL). The distribution of each parameter was assessed using the Kolmogorov–Smirnov test. For normally distributed variables, statistical comparisons between groups were made using 1-way analysis of variance (ANOVA) with the Bonferroni post hoc test. For parameters not normally distributed, statistical comparisons between groups were made using the Kruskal–Wallis test and post hoc Mann–Whitney *U* tests. The chi-square tests and independent *t* test were used to analyze the difference among age groups for the prevalence of different types of refractive errors, respectively. Correlations were used to compare the data between age with other parameters. Multivariate linear regression analysis with stepwise methods was then performed to assess the associations between SE, sex, AL, height, and weight. All *P* values were 2-sided and considered statistically significant when less than 0.05.

TABLE 2. *Visual Abnormalities in Right Eyes by Age*

Age (yrs)	Myopia n (%)	Hyperopia n (%)	Astigmatism n (%)
All	423 (5.9)	74 (1.0)	910 (12.7)
4	178 (5.7)	23 (0.7)	410 (13.1)
5	191 (5.8)	44 (1.3)	410 (12.5)
6	54 (7.1)	7 (0.9)	90 (11.9)
P	0.313	0.050	0.622
Boys	229 (6.0)	34 (0.9)	484 (12.7)
4	85 (5.1)	14 (0.8)	221 (13.4)
5	115 (6.5)	17 (1.0)	215 (12.2)
6	29 (7.2)	3 (0.7)	48 (11.9)
P	0.130	0.880	0.537
Girls	194 (5.8)	40 (1.2)	426 (12.7)
4	93 (6.3)	9 (0.6)	189 (12.7)
5	76 (5.0)	27 (1.8)	195 (12.9)
6	25 (7.1)	4 (1.1)	42 (11.9)
P	0.190	0.012	0.874

RESULTS

A total of 7,507 children in all the kindergartens were invited to participate in the study. Of these, 7,166 children successfully completed their refraction measurements, giving a response rate of 95.5%, including 3,813 (53.2%) boys. The demographic characteristics of the subjects were shown in Table 1. One thousand four hundred seven (19.6%) children were identified in having visual abnormalities including myopia, hyperopia, and astigmatism (Table 2).

Spherical Equivalent

As shown in Table 3, the median (interquartile range [IQR]) of SE for all the children was +0.25 D (−0.13 to +0.62 D), and the range was −15.88 to +18.13 D. Significant differences by age for SE were found in all the children ($P<0.001$), the boys ($P<0.001$), and the girls ($P<0.001$). Despite the significant age differences detected by the Kruskal–Wallis test, there was no significant correlation between SE with age ($R = -0.007$, $P=0.682$). There was

TABLE 3. *Spherical Equivalent in Right Eyes by Age*

Age (yrs)	Median	Minimum	25%	75%	Maximum
All	+0.25	−15.88	−0.13	+0.62	+18.13
4	+0.25	−8.00	−0.12	+0.62	+8.50
5	+0.25	−15.88	−0.19	+0.57	+10.38
6	+0.19	−12.00	−0.19	+0.50	+18.13
P	<0.001				
Boys	+0.25	−8.00	−0.12	+0.62	+18.13
4	+0.37	−8.00	0	+0.75	+8.37
5	+0.19	−5.94	−0.25	+0.50	+5.50
6	+0.13	−4.62	−0.19	+0.50	+18.13
P	<0.001				
Girls	+0.37	−15.88	−0.12	+0.75	+10.38
4	+0.37	−8.00	0	+0.86	+8.50
5	+0.25	−15.88	−0.12	+0.62	+10.38
6	+0.25	−12.00	−0.25	+0.56	+3.69
P	<0.001				

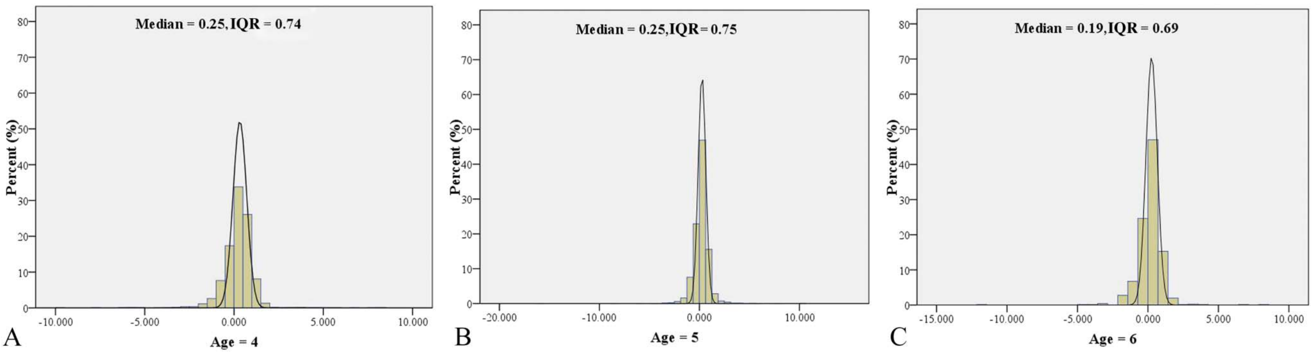

FIG. 1. Distributions of spherical equivalent by age. (A) 4 year-olds children; (B) 5 year-olds children; (C) 6 year-olds children. IQR, interquartile range. full color online

a significant difference in SE between boys and girls (the Mann–Whitney *U* test, $P<0.001$). A more hyperopic SE in girls was observed in two age groups ($P<0.001$ for 4-year-olds group and $P=0.001$ for 5-year-olds group), except in the 6-year-olds group ($P=0.887$). However, all these differences were too small to be of clinical significance. The distribution of refractive errors for each age group was shown in Figure 1.

Axial Length

As shown in Table 4, the mean AL for all the children was 22.35±0.70 mm, and the range was 18.20 to 27.71 mm. Significant differences by age for mean AL were found in all the children ($P<0.001$), the boys ($P<0.001$), and the girls ($P<0.001$). Despite the significant age differences detected by the ANOVA test, there was no significant correlation between mean AL with age (R = −0.004, $P=0.809$). There was a significant difference in mean AL between boys and girls (the independent *t* test, $P<0.001$). A shorter mean AL in girls was observed in all age groups (all $P<0.001$).

Prevalence of Myopia, Hyperopia, and Astigmatism

Myopia was uncommon in the preschool population (Table 2). Using this definition of SE of at least −1.00 D, the overall prevalence of myopia was 5.9% with noncycloplegic autorefraction. No significantly different prevalence rates with age were found in all the children ($P=0.313$), the boys ($P=0.13$), and the girls ($P=0.19$). The overall prevalence of myopia in the boys was similar to that in the girls ($P=0.693$ for the total sample, $P=0.174$ for 4-year-olds group, $P=0.063$ for 5-year-olds group, and $P=0.951$ for 6-year-olds group, respectively). In addition, there were eight children with high myopia.

TABLE 4. *Axial Length in Right Eyes by Age*

Age (yrs)	Mean	Minimum	SD	Maximum
All	22.35	18.20	0.70	27.71
4	22.23	19.00	0.70	27.71
5	22.42	18.20	0.68	25.19
6	22.57	19.69	0.70	24.51
P	<0.001			
Boys	22.59	19.16	0.68	27.71
4	22.46	19.16	0.70	27.71
5	22.66	20.16	0.64	25.19
6	22.83	19.69	0.66	24.51
P	<0.001			
Girls	22.08	18.20	0.63	24.33
4	21.98	19.00	0.60	23.80
5	22.15	18.20	0.63	24.33
6	22.27	20.08	0.63	23.96
P	<0.001			

The overall prevalence of hyperopia was 1.0% in children (Table 2). Significantly different prevalence rates with age were found in the girls ($P=0.012$), but there was no clear trend in all the children ($P=0.05$) and the boys ($P=0.88$). For example, the prevalence of hyperopia in the girls was 0.6% in 4-year-olds group, increased to 1.8% in 5-year-olds group, and then decreased again to 1.1% in 6-year-olds group. The overall prevalence of hyperopia in the boys was similar to that in the girls at all ages ($P=0.208$). When age groups were analyzed separately by sex, this trend was observed in the 5-year-olds group ($P=0.044$), but not in the 4-year-olds group ($P=0.431$) and 6-year-olds group ($P=0.578$). In addition, there were 14 children with high hyperopia.

The overall prevalence of astigmatism was 12.7% (Table 2). No significantly different prevalence rates with age were found in all the children ($P=0.622$), the boys ($P=0.537$), and the girls ($P=0.874$). With-the-rule astigmatism was overwhelmingly the most common type of astigmatism, followed by ATR astigmatism and oblique type, at all ages in both boys and girls (Table 5). The mean astigmatism in the right eyes measured by autorefractors were −1.55±0.69 D in all the children, −1.56±0.70 D in the boys, and −1.53±0.67 D in the girls, respectively. There were no statistically significant age effect on the prevalence of astigmatism for all the children ($P=0.384$), the boys ($P=0.142$), and the girls ($P=0.121$).

Height and Weight

As shown in Table 6, the median (IQR) of height for all the children was 111.0 cm (106.9 cm and 115.4 cm), and the range was 90.0 to 142.5 cm. Significant differences by age for height were found in all the children ($P<0.001$), the boys ($P<0.001$), and the girls ($P<0.001$). There was significant correlation between height with age (R=0.521, $P<0.001$). There was a significant difference in height between boys and girls (the Mann–Whitney *U* test, $P<0.001$). Girls were shorter than boys in all age groups ($P<0.001$ for 4-year-olds group, $P<0.001$ for 5-year-olds group, and $P=0.005$ for 6-year-olds group, respectively).

As shown in Table 7, the median (IQR) of weight for all the children was 19.0 kg (17.2 kg and 21.1 kg), and the range was 11.0 kg to 53.0 kg. Significant differences by age for weight

TABLE 5. *Astigmatism Type of the Right Eye by Age (D)*

Age (yrs)	WTR n (%)	ATR n (%)	Oblique n (%)
All	730 (10.2)	38 (0.5)	142 (2.0)
4	327 (10.4)	21 (0.7)	62 (2.0)
5	324 (9.9)	15 (0.5)	71 (2.2)
6	79 (10.4)	2 (0.3)	9 (1.2)
Boys	399 (10.5)	19 (0.5)	66 (1.7)
4	179 (10.8)	10 (0.6)	32 (1.9)
5	177 (10.1)	7 (0.4)	31 (1.8)
6	43 (10.6)	2 (0.5)	3 (0.7)
Girls	331 (9.9)	19 (0.6)	76 (2.3)
4	148 (10.0)	11 (0.7)	30 (2.0)
5	147 (9.7)	8 (0.5)	40 (2.6)
6	36 (10.1)	0 (0)	6 (1.7)

ATR, against-the-rule astigmatism; WTR, with-the-rule astigmatism.

were found in all the children ($P<0.001$), the boys ($P<0.001$), and the girls ($P<0.001$). There was significant correlation between weight with age (R=0.368, $P<0.001$). There was a significant difference in height between boys and girls (the Mann–Whitney *U* test, $P<0.001$). Girls were lighter than boys in all age groups ($P<0.001$ for 4-year-olds group, $P<0.001$ for 5-year-olds group, and $P=0.001$ for 6-year-olds group, respectively).

Multivariate Linear Regression Analysis Between Spherical Equivalent, Sex, Axial Length, Height, and Weight

After multivariate analysis, more myopic SE (or less hyperopic SE) was significantly associated with girls (standardized $\beta=0.009$, $P=0.003$), longer AL (standardized $\beta=-0.009$, $P=0.001$), taller (standardized $\beta=-0.434$, $P<0.001$), and lighter (standardized $\beta=0.542$, $P<0.001$).

DISCUSSION

This study documented the prevalence of various refractive errors in a rural region in Shanghai among children between 4- and 6-year-olds based on a 3-year public health program. This study indicated that a significant number of preschool children in Jinshan District had visual abnormalities including myopia, hyperopia, and astigmatism. The overall prevalence of myopia (−1.00 D or less), hyperopia (+2.00 D or greater), and astigmatism (1.00 D or greater) were 5.9%, 1.0%, and 12.7%, respectively. The most common type of refractive error was astigmatism, followed by myopia and hyperopia.

TABLE 6. *Height of the Participants*

Age (yrs)	Median	Minimum	25%	75%	Maximum
All	111.0	90.0	106.9	115.4	142.5
4	107.4	92.9	104.2	110.5	130.0
5	113.6	90.0	110.0	117.0	135.0
6	116.3	95.5	112.8	120.0	142.5
P	<0.001				
Boys	111.5	90.0	107.4	116.0	141.0
4	107.8	92.9	104.8	111.0	130.0
5	114.0	90.0	110.5	117.4	130.0
6	116.9	99.1	113.2	120.0	141.0
P	<0.001				
Girls	110.5	90.0	106.4	115.0	142.5
4	107.0	93.0	103.5	110.0	130.0
5	113.1	90.0	109.6	116.6	135.0
6	115.9	95.5	112.3	119.4	142.5
P	<0.001				

This study showed that myopia was uncommon in Chinese preschool children in the present population. The overall prevalence of myopia was 5.9%. The results obtained on this sample of preschool children from Shanghai differed markedly from those reported for Chinese children in Shandong, Guangzhou, Xuzhou, and Hong Kong. For example, the prevalence of myopia for 6-year-old (7.1%) children was higher than that in Shandong (4.1%),[5] Guangzhou (1.6%),[20] but lower than that in Hong Kong (17.0%).[11] The prevalence of myopia was also higher than that in India,[23] Chile,[24] Germany,[25] and America,[26,27] but lower than that in Singapore.[28] In comparison of prevalence rates among different studies, the differences in definition of refractive error and refractive error measurement techniques should be noted. Myopia was defined as at least −1.00 D in this study, similar to previous studies in America.[26,27] In this study, preschool children were examined with autorefractors under noncycloplegic condition. The accuracy of the Cannon RK-F1 autorefractor, which was widely used for vision screening, was effective for detecting significant refractive errors.[29] But autorefraction without cycloplegia could overestimate the prevalence of myopia in children.[30,31] Despite differences between these studies, there was a relatively higher prevalence of myopia in Chinese children, and the prevalence of myopia varied from districts and states. These differences were related to the environment including amount of near-vision work, education, outdoor activity level, and economic status. It is suggested that children in developed regions tend to be myopic. Shanghai is a developed city in eastern China, and children in Shanghai share most of the common characteristics similar to other East Asian countries with high prevalence of myopia, for example, living in the environments with competitive lifestyles, many interest classes, and heavy homework. In addition, the prevalence of myopia may still increase over time in China.

The overall prevalence of hyperopia was 1.0%, which was much lower than that in the previous studies.[5,20,23,24,26–28] Hyperopia was defined as at least +2.00 D in this study, similar to previous studies.[20,27] But some studies had different definition of hyperopia. For example, hyperopia was defined as SE of more than +0.50 D in Shandong,[5] at least +1.00 D in Baltimore,[26] and at least +3.00 D in Singapore.[28] Furthermore, noncycloplegic autorefraction in this study could underestimate the prevalence of hyperopia in children.[30,31] Because of low prevalence of hyperopia and characteristic of sensitive to environmental factors among preschool children, the young children are liable to become myopic and experience rapid myopia progression.

Astigmatism was found in 12.7% of the children, without significant differences among the different age groups, similar to that seen in the Guangzhou[20] and Suzhou[22] study. However, other population-based studies (Baltimore Pediatrics Eye Disease Study[26] and Multi-Ethnic Pediatric Eye Disease Study[27]) and nonpopulation-based studies (both cross-sectional[32] and longitudinal[11,33,34] studies) found a decreasing trend with age for astigmatism. With-the-rule astigmatism was the most common form in all the preschool children. A similar predominance of WTR astigmatism was seen in the population-based Baltimore Pediatrics Eye Disease Study,[26] Multi-Ethnic Pediatric Eye Disease Study[27] and

TABLE 7. *Weight of the Participants*

Age (yrs)	Median	Minimum	25%	75%	Maximum
All	19.0	11.0	17.2	21.1	53.0
4	17.8	11.5	16.3	19.5	51.0
5	20.0	11.0	18.1	22.0	53.0
6	20.8	13.8	19.0	23.4	44.0
P	<0.001				
Boys	19.3	12.5	17.5	21.6	51.0
4	18.0	12.9	16.6	19.8	51.0
5	20.2	12.5	18.4	22.5	45.9
6	21.2	13.8	19.3	24.0	37.5
P	<0.001				
Girls	18.6	11.0	17.0	20.6	53.0
4	17.5	11.5	16.0	19.0	48.0
5	19.5	11.0	17.8	21.4	53.0
6	20.2	14.2	18.6	22.6	44.0
P	<0.001				

STARS[28] among preschool children, and in some nonpopulation-based studies.[35] Moreover, Gwiazda et al.[36] reported a shift in the predominance of ATR astigmatism in younger children to predominance of WTR astigmatism in older children. A change trend for astigmatism and its subgroups were not found in this study.

In this study, multivariate analysis revealed that myopia was associated with girls, similar to the findings in previous studies.[5,6,15] However, a meta-analysis found that sex was not a predictor for myopia in Asia.[37] But the effect of sex on myopia remains unclear. Puberty may play an important role in refractive development. Girls might be more likely to be affected by myopia at an earlier age, rather than more susceptible to myopia.[38]

The relationship between more myopic SE (or less hyperopic SE) and taller found in this study was also reported in population-based studies on children.[39] It may reflect a general association between height and size of the ocular globe. Furthermore, the result that SE correlated positively (but weakly) with weight was similar to the finding reported by Saw et al.[40] However, Chen et al.[41] found that refraction progression was positively associated with the change of height and weight. In addition, SE was not significantly correlated with age in the study, which may be due to a very small age span. These results were in good agreement with the finding in Chinese children aged from 3 to 6 years reported by Lan et al.[20] The reason for the discrepancy between these studies might be also confounded by parameters of the socioeconomic background, which was not taken into account in this study.

There were some limitations in this study. First, attempts to measure refractive status without cycloplegia using autorefractors could lead to significant errors, such as an overestimation of myopia and underestimation of hyperopia because of the strong accommodative reserve, especially in children younger than 12 years.[42] However, without cycloplegia, the procedure was simple and time-saving, and did not require additional personnel to administer the cycloplegic agents. Second, only one district, Jinshan, was included in the study. Therefore, the prevalence of refractive errors in this study could not be representative of the whole of Shanghai.

In conclusion, Shanghai has a high prevalence of refractive error in the world. The marked increase in the prevalence of myopia in the young generation of China will be of importance for future public health politics. However, longitudinal studies are needed to evaluate refractive changes over time in individual children, and more studies on the interaction between genetic and environmental factors are warranted to prevent the development of myopia.

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