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Significant increase in astigmatism in children after study at home during the COVID-19 lockdown

Short title: Increase in astigmatism after study at home

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Abstract

Clinical relevance: Compared to previous epidemiological studies on Hong Kong children, this study shows a significant increase in refractive astigmatism after "study at home" during the COVID pandemic. These results underscore the importance of health service and clinical management to cope with the surge in refractive error development.

Background: To investigate whether there has been a change in the proportion of astigmatism among primary school children after the school closure period during the COVID-19 pandemic.

Methods: This observational study compared cross-sectional (2018: n = 112; 2020: n =173) and longitudinal data (n = 38) collected from two vision screenings, one in 2018 and the other after the school closure period in 2020, in the same primary school for children aged 8-10 years. Non-cycloplegic refraction and axial length were measured by an open-field auto-refractometer and IOL Master, respectively. A questionnaire focusing on demographic information, near-work time, and outdoor activities was administered to parents of all participants.

Results: While there were no significant differences in age, gender, or monthly family income between the two cohorts, astigmatism proportion (Cyl ≥ 0.75 D) in 2020 was 1.5-fold higher than that in 2018 (56.6% vs. 35.4%). The median cylindrical power was significantly higher in 2020 in older children (9- or 10-year-old). More importantly, the children participating in both vision screenings had cylindrical power and J0 astigmatism significantly increased by 0.35±0.40 D and 0.21±0.25 D.

Conclusion: A significant increase in astigmatism (both proportion and magnitude) was found after the school closure period. Further studies are needed to investigate the origin of this increased astigmatism.

Introduction

Astigmatism is a common refractive error that affects 28% (Cyl ≥ 1D) of schoolchildren in the United States[1] and 23% to 58% (Cyl ≥ 0.75D) in urban areas of Asian countries.[2] Notably, uncorrected astigmatism at a young age can adversely interrupt normal visual development, leading to permanent orientation-dependent visual deficits, i.e., meridional (or astigmatism-related) amblyopia.[3] Astigmatism is also associated with migraine headaches[4] and a weaker retinal electrophysiological response[5] even after optical correction.

While the aetiology of astigmatism remains unclear, both laboratory and clinical evidence indicate either direct or indirect contributions of the visual environment to its development. First, as revealed by animal studies, the eyes can, at least partially, counterbalance imposed astigmatic defocus (i.e., the orientation-dependent blur) by developing compensatory refractive astigmatism.[6,7] Second, astigmatism frequently coexists with spherical ametropias (i.e., myopia and hyperopia),[8] and the magnitude of astigmatic error often correlates with that of myopia and hyperopia in both children and adults.[9,10] Thus astigmatism may be indirectly induced as a by-product of this vision-dependent axial elongation process.[11,12] Animal studies have shown that astigmatism is often accompanied by spherical ametropia in eyes treated with spherical defocus or form deprivation.[12,13] Finally, near-work activities can induce transient astigmatism, probably due to eyelid pressure exerted onto the cornea.[14] This induced astigmatism is more noticeable when the visual task requires more downward gaze, such as reading and smartphone usage.[14]

During the COVID-19 pandemic, all aspects of daily life have been changed significantly, including the way children receive education. To contain the spread of infection, most governments worldwide enforced school closures, which are estimated to have affected over 80% of the global student population.[15] In Hong Kong, schools were encouraged to integrate e-learning platforms during school closure, with online resources to facilitate children learning at home. The city lockdown and social distancing policies amid the COVID compelled children to stay at home for much of the day, reduced their outdoor time, and indirectly encouraged them to spend more time on near-work and digital screens, which could all influence normal refractive development.[16] However, it is unclear whether there is a change in the incidence and severity of astigmatism in primary school children after school closure during the COVID-19 pandemic.

This study compared the cross-sectional results of two vision screenings conducted in the same local primary school, one in 2018 and the other in 2020 after the school closure, for primary school children aged 8-10 years. Longitudinal data from 38 schoolchildren who participated in both vision screenings were also analysed.

METHODS

Vision Screening Population

Two surveys were conducted in a Hong Kong government-funded primary school located in the city centre, the first in October 2018 and the second in June 2020. During the COVID-19 pandemic, all primary schools in Hong Kong enforced a "school from home" policy for about 4 months, between February and June 2020. The first survey was conducted as part of a separate research study, without any expectation of the pandemic. The second survey was conducted on children of the same age groups (only 38 children overlapped with the first survey) 2 weeks after school reopening. In 2018, a vision survey was conducted for Grades 2-5 schoolchildren. Initially, we intended to conduct another vision survey for these 4 years of classes in 2020. However, because of the tight teaching arrangement after school closure, Grade 5 children in the 2020 cohort, who had to prepare for the secondary school entrance examination, could not participate in the vision survey. Thus, only children aged 8-10 years old, an age range covering both cohorts, were included for analysis. The inclusion criteria for both surveys were 1) Chinese primary school children; and 2) aged between 8 and 10 years old. Children in this age range were also selected because they are known to exhibit rapid eye growth.[17] Data collected from children under any optical or pharmacological myopia control intervention were excluded from further analyses. Informed written consent was obtained from parents after explaining the nature and purpose of the study. The study followed the tenets of the Declaration of Helsinki and was approved by the ethics committee of The Hong Kong Polytechnic University (HSEARS20180726001 and HSEARS20190625001).

Vision Screening Procedures

In both vision screenings, the same ophthalmic instruments and school settings were adopted. The eye examination was conducted at the school campus on school-day mornings from 9 am to 12 pm, when regular teaching activities were usually conducted. The vision screening tests took each student no more than 20 minutes.

Each child underwent monocular distance habitual visual acuity (VA) measurements (unaided and aided where applicable) using Early Treatment Diabetic Retinopathy Study (ETDRS) acuity charts (Precision Vision, La Salle, IL). Non-cycloplegic refraction was carried out using an open-field auto-refractometer (Shin-Nippon, NVision-K 5000, Japan). Children were instructed to fixate at a target (Maltese cross) at 6 m under normal room lighting (approximately 400 lux). Five consecutive readings of each eye were obtained and averaged. The measurement was performed without the administration of cycloplegia to avoid interfering with classroom learning during the school day and to increase the participation rate. Ocular axial length was measured using an IOL Master (Carl Zeiss Meditec, Jena, Germany). The averaged value of five consecutive measurements with signal-to-noise ratios > 2.0 was used for the analysis. Both devices were calibrated using a proprietary model eye specific to the instruments on a daily basis.

Administration of Questionnaire

A validated, self-administered questionnaire was distributed via the school teachers to parents of participants and collected before the eye examination in both surveys. The questionnaire covered basic demographic information, ocular health history, family income, and parental myopia. In addition, it also included questions related to children's visual habits, i.e., the average time per day children engaged in non-screen near work (reading and writing on paper materials), handheld digital screen work (smartphones and tablets), and outdoor activities during the non-school hours on weekdays and on weekends. These questions were developed by referring to published data related to myopia risk factors.[18,19] The comprehensibility of the questionnaire was first tested on eight parents via a face to face interview at the optometry research clinic in the Hong Kong Polytechnic University. The repeatability of the questionnaire was then tested by asking 20 parents to complete the same survey with a two-week interval between them and was found to have a high intraclass correlation (ICC = 0.96, $p < 0.001$).

Statistical Analysis

Refractive errors were decomposed into spherical-equivalent refractive error (SE) and J0 and J45 astigmatic components according to Fourier analysis.[20] Only data from the right eye was used because refractive and biometric parameters of the right and left eyes were highly correlated (Pearson's correlations, $r \geq +0.87$, $p < 0.001$). Refractive astigmatism was defined as a cylindrical error ≥ 0.75 D. Because of the relatively small sample sizes, the term astigmatism "proportion" rather than "prevalence" was used in the results section.[21] Astigmatism was classified into With-The-Rule (WTR, axis: 0°-

30° or 150°-180°), Against-The-Rule (ATR, axis: 60°-120°), and oblique astigmatism (OBL, axis: 30°-60° or 120°-150°) according to the axis of the negative correcting cylinder.

Statistical analyses were performed using the Statistical Package for Social Science (version 22, IBM Corp., NY, USA) with the significance level set at $\alpha < 0.05$. For the cross-sectional data, continuous variables collected in 2018 and 2020 for each independent age group were compared with either unpaired t-test or Mann-Whitney U test, depending on normality tested by the Shapiro-Wilk test. A chi-squared test was used to compare categorical variables between groups. Continuous variables of the longitudinal data were tested with paired t-test or Wilcoxon signed-rank test. An exact McNemar test was conducted to analyze astigmatism proportion between the two vision screenings.

RESULTS

Participants' Demographic Information

Figure 1 illustrates the flowchart of this study. In the 2018 survey, of the 264 students invited to join the study, 179 participated (67.8% response rate). In the 2020 survey, 236 students were invited, and 207 participated (87.7% response rate). The following analyses were conducted only for those who participated in the vision screening and returned their questionnaires (2018: n=112; 2020: n=173).

Participates' demographic information is summarized in Table 1. There were no significant differences in age, gender, and family income between the two cohorts (all $p > 0.05$). Parental myopia was also similar between the two cohorts (all $p > 0.05$), except for the 8-year-old group in 2020, who had more myopic parents than those in 2018 (Chi-squared test, $\chi^2 = 7.19$, $p = 0.007$).

Cross-sectional Survey Data

Astigmatism, Myopia & Axial Length

Overall, the proportion of astigmatic children was significantly higher in the 2020 cohort (56.6%, 95% CI: 49.8-68.0%) compared to the 2018 cohort (35.4%, 95% CI: 21.4-49.5%) (Chi-squared test, $\chi 2 = 7.20$, p = 0.007). Figure 2A illustrates the frequency distribution (percentage) of cylindrical power in 2018 (blue bars and line) and 2020 cohorts (red bars and line). In 2018, the data clustered at a lower cylindrical error, whilst in 2020 the distribution shifted to higher cylindrical powers and the astigmatism proportion was approximately 1.5-fold higher. Figure 2B shows the proportion of astigmatism in individual age groups. The proportion of astigmatism was generally higher in 2020 than in 2018. However, the difference was significant only for the 10-year-old group (Chi-squared test, $\chi^2 = 5.28$, $p = 0.022$) but the changes did not differ significantly for either the 8- (Chi-squared test, $\chi^2 = 0.28$, $p = 0.60$) or 9-year-old groups (Chi-squared test, $\chi^2 = 2.63$, $p = 0.11$). Among the astigmatic children in 2018 (n = 37) and 2020 cohorts (n = 85), WTR astigmatism predominated (Figure 3), accounting for over 89% of the astigmatic children in both cohorts.

The magnitude of refractive astigmatism in the older age groups was significantly higher in 2020 than in 2018 (Table 2 and Figure 4). As shown in Figure 4A, 9- and 10-year-old children participating in the 2020 survey had significantly higher cylindrical powers than those in the 2018 survey (Mann-Whitney U tests, $U = 1180$ and 2309, $p < 0.05$). Likewise, J0 astigmatism was more positive in 2020 than in 2018 (Figure 4B), although the difference was significant only for the 10-year-old (Mann-Whitney U tests, $U = 1255$, $p = 0.004$) but not the 9-year-old group ($U = 721$, $p = 0.06$). In contrast, 8-year-old children participating in the 2020 survey had more positive J45 astigmatism (Figure 4C, Mann-Whitney U tests, $U = 319$, $p < 0.001$) than those in the 2018 survey, but these differences were not significant in the older age groups (*U* = 837 and 1689, $p \geq 0.37$).

In addition to astigmatism, children participating in the 2020 survey tended to have more myopia (Table 2, Mann-Whitney U test, $U > 906$, $p \leq 0.001$), worse habitual VA (Mann-Whitney U test, $U \geq 432.5$, $p \leq 0.033$) and longer axial length (unpaired t-test, $t \geq -1.96$, $p \geq 0.056$), but the latter (axial length) did not reach statistical significance. As expected, the axial length was inversely correlated with the SE (2018: Pearson's $r = -0.61$, $p < 0.001$; 2020: Pearson's $r = -0.67$, $p < 0.001$).

Visual Habits

According to the questionnaire data (Table 3), children in the 2020 cohort spent 0.50 to 1 hr/day more time on handheld digital devices (including smartphones and tablets) on both weekdays and weekends for all (Mann-Whitney U test, $U = 377.5$, $p \leq 0.023$) except at weekends for the 9- and 10-year-old groups (Mann-Whitney U test, $U = 752$, $p \leq 0.31$). In contrast, children in the 9-year-old group spent less time on non-screen work in 2020 than in 2018, but the difference was significant only for weekdays (Mann-Whitney U test, $U = 516.5$, $p = 0.003$). There was generally no significant difference in the outdoor time between the 2018 and 2020 cohorts (Mann-Whitney U test, $U = 882$, $p \leq 0.94$), except that 10-year-old children participating in the 2018 survey spent more time on outdoor activities during weekdays ($U = 1048.5$, $p = 0.023$).

Longitudinal Survey Data

Astigmatism, Myopia, & Axial Length

Among the 112 schoolchildren who participated in the 2018 survey, 38 children (Female: Male = 17:21), all aged eight years in 2018, also attended the vision screening in 2020. An exact McNemar test revealed a statistically significant difference in the proportion of astigmatic children between 2018 (34.2%, 95% CI [19.1 – 49.3%]) and 2020 (73.7%, 95% CI [59.7 – 87.7%]; $\chi^2 = 10.31$, $p = 0.001$). The longitudinal change of refractive errors in this subgroup concurs with the trend shown in the cross-sectional data, showing a significant increase in the magnitude of astigmatism and its vector component: the cylindrical power was on average increased by 0.35±0.40 D (Figure 5A, paired t-test, $t = 5.53$, $p < 0.001$) and J0 astigmatism become more positive by 0.21±0.25 D (Figure 5B, $t = 5.01$, $p < 0.001$). In contrast, the J45 astigmatism appeared to be less negative, by 0.05±0.19 D (Figure 5C, $t = 1.79$, $p = 0.08$), but the change did not reach statistical significance. Myopia and axial length were both increased significantly, by 1.63±0.61 D and 0.53±0.30 mm, respectively (paired t-test, $t = -16.40$ & 11.00, both $p < 0.001$).

Visual Habits

Table 4 summarizes the questionnaire data for children participating in both the 2018 and 2020 surveys. However, there were no significant differences in their time spent on near-work or outdoor activities (Wilcoxon signed-rank tests, $Z = 0.019$, $p \leq 0.98$).

DISCUSSION

This study showed that, compared to data collected in 2018, the astigmatism proportion of all schoolchildren participating in the 2020 survey was approximately 1.5-fold higher (56.6 % vs. 35.4%), especially for the 10-year-old children, which showed statistically significant difference. The average magnitude of astigmatism was also significantly higher in 2020 than in 2018, with more differences in the 9- and 10-year-old children. Due to the paucity of data on the prevalence of astigmatism for this age range in Hong Kong, for comparison purposes we could only approach the investigators who have unpublished data from a local epidemiological study conducted on schoolchildren between June 2015 and February 2016.[22] A retrospective analysis of their unpublished data showed that, of the 345 10-year-old schoolchildren surveyed, 35.1% (CI: 30.0-40.4%) had astigmatism (Cyl ≥ 0.75D), similar to the proportion of astigmatism we found in the 2018 cohort (35.4%, CI: 21.4-49.5%) but lower than the 2020 cohort (56.6%, CI: 49.8–68.0%).

In addition to the trend we observed from the cross-sectional data, longitudinal data collected from 38 schoolchildren participating in both vision screenings also indicated that both cylindrical power and J0 astigmatic component were on average increased by 0.35 D and 0.20 D, respectively, during the 18 months follow-up period. It has been shown that even a small amount of uncorrected astigmatism (~ 0.50D) is associated with migraine[4] and asthenopic symptoms.[23] Parents should pay attention to possible refractive error changes in children amid the COVID pandemic for timely eye care, especially when children behave abnormally or encounter any visual problems.

The increase in astigmatism found in the current study contradicts previous longitudinal studies, which reported either a drop in or stable astigmatism during childhood. Chan et al.[24] monitored the refractive changes of Chinese children (aged 9.04±1.38 years, n = 183) from a primary school in Taiwan. The baseline cylindrical power of their participating children (0.74±0.81 D) was comparable to those in the current study (0.77±1.00 D), but they reported a drop in astigmatism to 0.58±0.61 D rather than an increase in astigmatism a year later. In addition, Fan et al.[25] who followed the refractive status of a group of younger children in Hong Kong after five years (age: 9.3±0.89 years, n = 108), observed a decrease in cylindrical power from 0.62±0.43 D to 0.50±0.49 D. The drop in astigmatism during childhood reported by previous studies is also independent of ethnicity.[26,27] As such, the unusual increase in astigmatism (proportion and magnitude) found in the current study suggests that children in the 2020 cohort might have been exposed to undetermined risk factors.

In the current study, confirmation was received from school teachers that the classroom activities and curriculum had not changed over the last two years, except integrating e-learning platforms for students to study at home during the school closure. Because there were no significant differences in family incomes, gender and age between the two cohorts for the 9- and 10-year-old children (Table 1), it is less likely that participants' demographic variation could explain the increased astigmatism proportion in these two age groups. In contrast, children in the 2020 survey had engaged in significantly longer handheld digital screen time than those in the 2018 survey. Although the difference was not significant in the longitudinal data, the “screen time” in this study only referred to the non-school hours, i.e., it did not include the time spent on online learning, which was usually another four hours/day on weekdays. However, it requires further studies to investigate whether digital screen usage directly impacted astigmatism development.

Previous studies have reported that near-work that requiring a downward gaze usually induced against-the-rule astigmatism with the negative cylindrical axis oriented close to 90^{o}.[14] However, although children in the 2020 cohort spent more time on digital devices, the near-work induced against-the-rule astigmatism is unlikely to explain the increased with-the-rule astigmatism in schoolchildren. First, the cross-sectional data reveals that with-the-rule astigmatism predominated (Figure 3). Second, both cross-sectional and longitudinal data indicate an increase in with-the-rule astigmatism.

It has been hypothesized that astigmatism is developed as a by-product of myopia progression.[11,12] To test the association between astigmatism and myopia, we further analyzed the longitudinal data and found a significant correlation between the change in SE and cylinder power (Pearson’s $r = +0.34$, $p = 0.038$), suggesting that the increased astigmatism was associated, though weakly, with myopia progression. However, the correlation between axial elongation and the change in cylinder power was not significant (Pearson's *r* = +0.30, *p* = 0.070). Because of the small sample size (n=38) and the relatively weak or non-significant relationships, further studies are warranted to investigate the relationship between astigmatism and myopia progression.

Besides the changes in astigmatism proportion, we also observed an increase in myopia magnitude and proportion for all three age groups in 2020 rather than in 2018. Except the possible influence of digital device use during childhood,[27] other lifestyle changes might also explain our results. For example, apartment size is generally small in Hong Kong with an average living space per person of only 13.3 m^2 public housing.[29] Due to COVID, children were forced to stay in the packed living environment, which has recently been shown to be associated with a longer axial length and more myopia.[22] Lack of outdoor time has also been shown to increase the risk of myopia.[30,31] While no difference was found about outdoor time between the two cohorts (except weekdays for the 10-year-old group), our questionnaire only asked about outdoor time outside school hours but did not consider the traveling time to and from school and outdoor time during the school hours (e.g., class break and outside physical education). Thus, the total outdoor time in the 2018 cohort may be underestimated, and insufficient outdoor activities could be an alternate explanation for the increase of myopia. Moreover, the 8-year-old children in the 2020 group had a higher parental myopia than the 2018 group (81.4% vs. 51.7%), suggesting more genetic contribution to the higher myopia prevalence in this cohort.[32] We cannot rule out the possibility that other lifestyle changes during the COVID pandemic, such as lack of exercise,[33] closer near-work distance due to more handheld digital devices usage,[34] and change in diet,[35] might also play a role, further studies are needed to confirm this relationship. Even though the two surveys were conducted in different quarters of the year (October 2018 and June 2020), it is less likely that our results were due to seasonal variation in refractive changes:

according to Gwiazda et al,[36] myopia incidence was higher in the winter than in the summer, in contradict to the trend shown by our results. Nevertheless, it should be cautious when interpreting the myopia changes in our study because the non-significant increase in axial length suggests the possibility of an accommodative aftereffect due to non-cycloplegic refractions.

Both cross-sectional and longitudinal data consistently showed that astigmatism was increased in schoolchildren during the study period. However, this study is still subject to several limitations. First, cycloplegic refractions were not used in either vision screening. Instead, an open-field auto-refractometer with a distant visual target was used to reduce accommodation. This procedure cannot exclude the possibility that the measured spherical ametropia was affected by ocular accommodation. Nevertheless, non-cycloplegic refraction has a minimal effect on astigmatism.[37] Previous study found that the differences in J0 and J45 astigmatism of children measured with and without cycloplegia were -0.08±0.13 D and -0.01±0.09 D, respectively,[37] whereas the astigmatic changes observed in the current study were >4 fold greater. Moreover, as reported by a previous study, each dioptre of accommodation only induced 0.036DC of astigmatic change.[38] Another study that included children aged 5.0-11.6 years old also showed that the changes in J0 (3D demand: -0.02 ± 0.00D; 6D demand: -0.03± 0.00D) and J45 (3D demand: -0.02 ± 0.00D; 6D demand: -0.01± 0.00D) were small even with high accommodative demands (i.e. 9D demand; J0: -0.04± 0.00D, J45: -0.03 ± 0.00D).[39] Thus, we believe that accommodation aftereffect cannot fully explain the increase of astigmatism in this study. Second, the sample sizes of both cohorts were not large. Additional vision screenings are urgently needed to confirm whether our results are generalizable to other ages and school populations. Third, the participation rate in 2020 was higher than that in 2018 (87.7% vs. 67.8%). It could be due to the parents' concerns of increasing near work activities during the 'study from home' period or the demands for an eye examination to prepare for school re-opening. Fourth, although administering a questionnaire is a convenient and efficient way to collect visual habits information from a large group of participants, it is subject to recall bias.[18] Recently, other objective method, such as the Clouclip,[40] has been developed to objectively and continuously record near work duration, viewing distance, and ambient light intensity by clipping the sensor to the temple of children's spectacle.[40] Lastly, it should be noted that the "study from home" period only lasted for 4 months before the second vision survey. Because there was no control group available for comparison, this study cannot confirm whether the observed changes were due to the lockdown or other factors. A direct impact due to this short interval on refraction and axial length in young school children must therefore be interpreted cautiously.

CONCLUSION

To conclude, vision surveys conducted in the same school separated by 2 years showed that the proportion of astigmatism in 8-10 years old children was approximately 1.5-fold higher. While data associated with myopia needs to be interpreted with caution because of the limitation in the experimental design, these results underscore the importance of health service planning to cope with the possible increased demand for vision care after the pandemic. Parents and guardians are advised to pay attention to their children's visual habits occasioned by the significant changes in their study pattern. More vision screenings and health education are needed to detect any significant refractive-error changes and foster a healthy visual hygiene in children.

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Table 1. Demographic information (±95% confidence intervals) of participants from 2018 to 2020 studies in the three age groups.

	8-year-old			9-year-old			10-year-old		
	2018	**2020**	*P value*	**2018**	**2020**	*P value*	**2018**	**2020**	*P value*
Sample size	29	43		35	54		48	76	
Boys (%)	51.7 (32.4, 71.1)	55.8 (40.3, 71.3)	0.73	34.3 (17.7, 50.8)	51.9 (38.1, 65.6)	0.10	50.0 (35.3, 64.7)	57.9 (46.5, 69.3)	0.39
Monthly Family Income (%)			0.96			0.12			0.72
≤ HK$19,999†	51.7 (32.4, 71.1)	51.2 (35.6, 66.7)		54.3 (36.9, 71.6)	70.4 (57.8, 83.0)		66.7 (52.8, 80.5)	69.7 (59.2, 80.3)	
> HK$19,999†	48.3 (28.9, 67.6)	48.8 (33.3, 64.4)		45.7 (28.4, 63.1)	29.6 (17.0, 42.2)		33.3 (19.5, 47.2)	30.3 (19.7, 40.8)	
Parental Myopia (%)#	51.7 (32.4, 71.1)	81.4 (69.3, 93.5)	0.007	62.9 (46.0, 79.7)	53.7 (40.0, 67.4)	0.39	58.3 (43.9, 72.8)	46.7 (35.1, 58.2)	0.21

†HK $19,999 was chosen because it was the median income level in our sample. Hong Kong median monthly domestic household income in 2018 was HK $28,300 according to the Hong Kong Census and Statistics Department.

#refers to at least one parent with myopia / high myopia.

Table 2. Cross-sectional data of refractive-error components [Median (IQR)] and axial length (Mean±SD) in the three age groups.

	8-year-old			9-year-old			10-year-old		
	2018	**2020**	*P value*	**2018**	**2020**	*P value*	**2018**	**2020**	*P value*
Habitual VA (logMAR)	0.08 (0.02, 0.14)	0.14 (0.06, 0.24)	0.028	0.06 (0, 0.16)	0.12 (0.04, 0.26)	0.033	0.03 (0, 0.16)	0.12 (0.03, 0.24)	0.040
M (D)	-0.31 (-1.16, 0.16)	-1.19 (-1.81, -0.93)	0.001	-0.31 (-1.50, +0.12)	-1.47 (-2.21, -1.06)	0.001	-0.23 (-1.56, +0.19)	-1.53 (-2.53, -1.00)	<0.001
Axial length (mm)	23.15±0.87	23.47±0.94	0.15	23.43±0.96	23.62±0.84	0.34	23.48±0.83	23.81±1.02	0.059
Cylinder Power (D)	0.62 (0.31, 0.81)	0.62 (0.37, 0.87)	0.37	0.50 (0.25, 1.00)	0.62 (0.50, 0.87)	0.047	0.50 (0.28, 0.97)	0.75 (0.53, 1.09)	0.013
J0 (D)	+0.20 (+0.12, +0.40)	+0.25 (+0.17, +0.42)	0.37	+0.17 (0, +0.47)	+0.28 (+0.18, +0.40)	0.060	+0.16 (0, +0.43)	+0.36 (+0.17, +0.53)	0.004
J45 (D)	-0.08 (-0.15, 0)	+0.03 (-0.04, +0.15)	<0.001	-0.01 (-0.14, +0.05)	0.00 (-0.09, +0.09)	0.36	-0.05 (-0.12, +0.03)	-0.03 (-0.14, +0.06)	0.49

** The corresponding sphero-cylindrical prescriptions converted from the averaged M, J0, & J45 in this table (2018 vs. 2020):*

- *8-year-old: -0.09/-0.43×169 vs. -0.94/-0.50×3*
- *9-year-old: -0.14/-0.34×178 vs. -1.19/-0.56×180*
- *10-year-old: -0.06/-0.34×172 vs. -1.17/-0.72×178*

- **Table 3.** Time spent on various activities [Median (IQR)].

	8-year-old			9-year-old			10-year-old		
	2018	**2020**	*P value*	**2018**	**2020**	*P value*	**2018**	**2020**	*P value*
Non-screen time (hour/day) (near work)‡									
Weekday	1.00 (0.50, 2.00)	1.00 (1.00, 2.00)	0.73	2.00 (1.50, 3.00)	1.50 (1.00, 2.00)	0.003	1.30 (0.65, 2.75)	1.00 (0.50, 2.00)	0.14
Weekend	1.00 (0, 2.00)	1.00 (1.00, 2.00)	0.22	2.00 (1.00, 2.00)	1.75 (1.00, 2.00)	0.88	1.50 (0, 2.75)	1.00 (0.50, 2.00)	0.48
Handheld digital screen time (hour/day)									
Weekday	1.50 (0.73, 2.00)	2.00 (1.00, 4.00)	0.014	1.00 (0.50, 2.00)	2.00 (1.50, 3.00)	<0.001	1.00 (0.50, 2.00)	2.00 (1.00, 3.00)	0.002
Weekend	2.00 (0.80, 3.00)	3.00 (1.50, 5.00)	0.023	2.00 (1.00, 3.88)	2.25 (1.88, 4.00)	0.31	2.00 (1.00, 3.25)	2.25 (1.25, 4.00)	0.23
Outdoor time (hour/day)									
Weekday	0.50 (0, 0.50)	0.50 (0, 1.50)	0.37	0.50 (0, 0.50)	1.00 (0, 1.00)	0.054	0.50 (0, 0.50)	1.00 (0, 1.00)	0.023
Weekend	2.50 (0.50, 2.50)	1.00 (1.00, 2.00)	0.068	1.50 (0.50, 2.50)	2.00 (1.00, 2.00)	0.94	1.50 (1.00, 2.50)	1.50 (0.50, 2.00)	0.20

‡ *refers reading and writing on paper materials, etc.*

Table 4. Time spent on different kinds of activities [Median (IQR)] for children participating both 2018 and 2020 surveys.

		2018	**2020**	*P value*
Non-screen time (hr/day)				
	Weekday	1.00 (0.50, 2.00)	1.00 (0, 2.00)	*0.43*
	Weekend	1.50 (0.50, 2.00)	1.00 (0.00, 2.00)	*0.50*
Handheld digital screen time (hr/day)				
	Weekday	1.50 (1.00, 2.00)	2.00 (1.00, 3.00)	*0.15*
	Weekend	2.00 (1.00, 3.00)	2.50 (2.00, 4.00)	*0.30*
Outdoor time (hr/day)				
	Weekday	0.50 (0.50, 1.50)	1.00 (0, 1.13)	*0.98*
	Weekend	2.50 (1.50, 2.50)	2.00 (1.00, 2.00)	*0.33*

Figure Captions

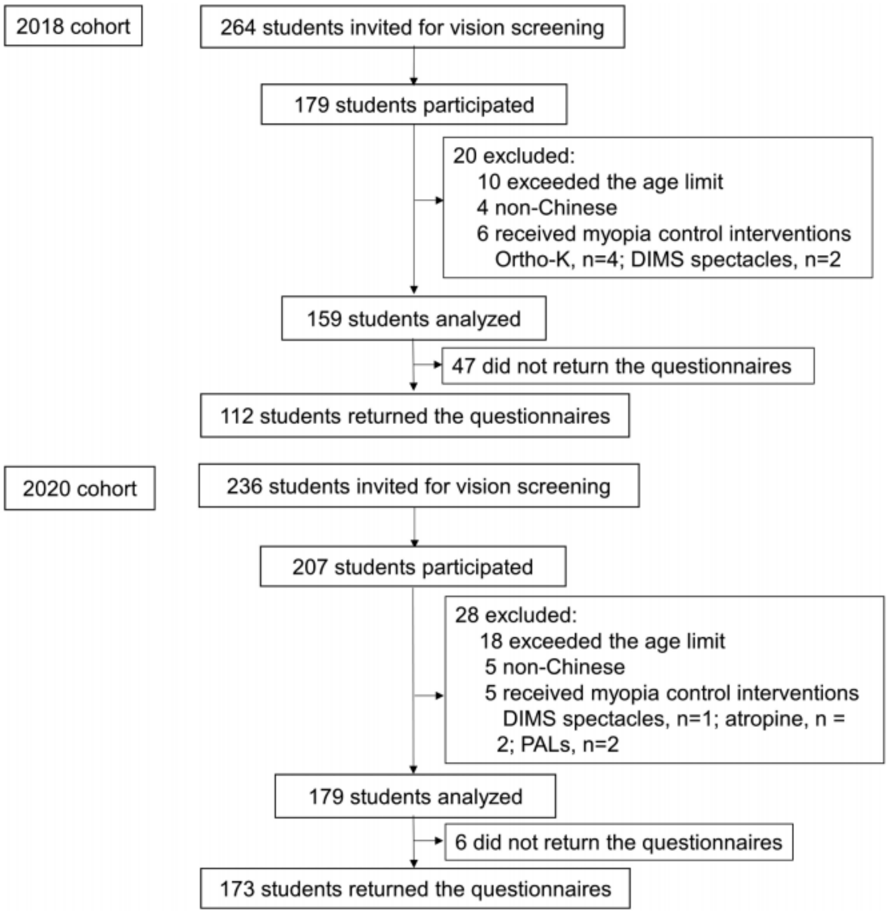

Figure 1. The flowchart of subject recruitment for 2018 and 2020 cohorts. Ortho-K: orthokeratology; DIMS spectacles: Defocus-Incorporated-Multiple-Segments spectacles; PALs: Progressive Addition Lens.

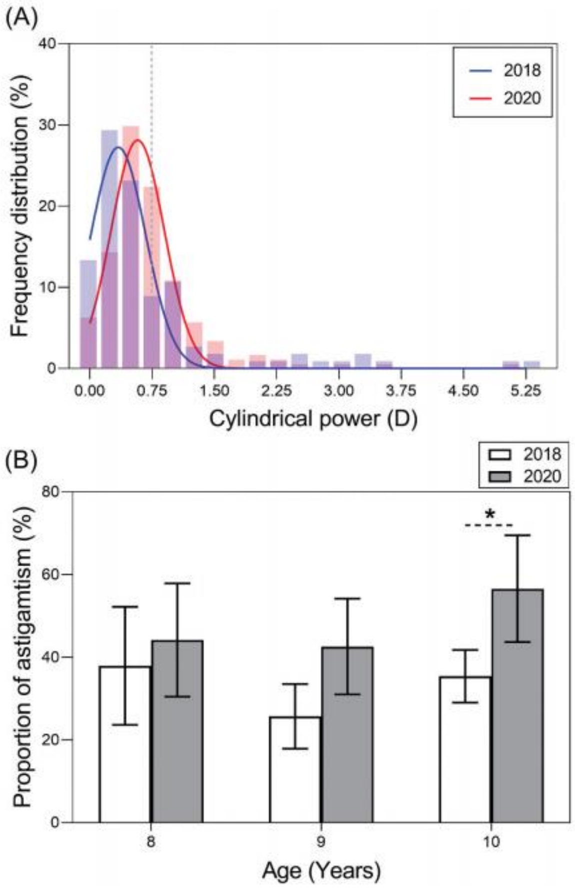

Figure 2. Frequency distributions of astigmatism for 2018 and 2020 cohorts. (A) Frequency distribution of cylindrical error with 0.25 D bin-width. Blue and red bars represent frequency distribution of the data collected separately from 2018 and 2020 surveys. The dashed line marks the definition of astigmatism (Cyl ≥ 0.75 D); all data on the right-hand side of this dashed line are classified as astigmatic. The distributions are fitted with curves using the Gaussian function. (B) Proportion of astigmatism (Cyl ≥ 0.75 D) (±95% confidence intervals) as a function of age. White and grey bars represent data collected from 2018 and 2020 surveys, respectively. Chi-squared test *, $p < 0.05$.

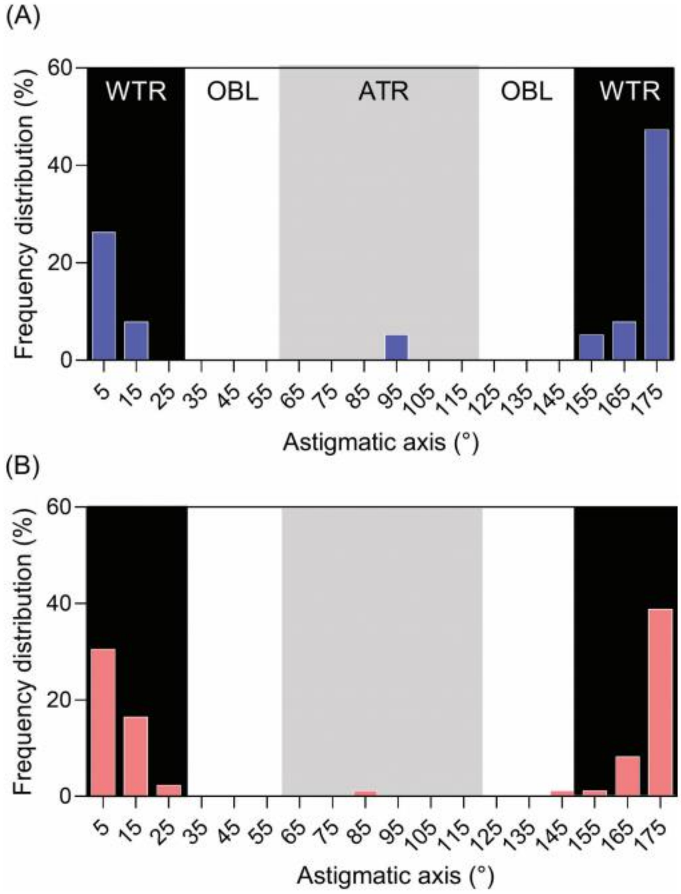

Figure 3. Frequency distribution of astigmatic axis. Proportions of astigmatism per 10°-bin width for 2018 (A, blue bars) and 2020 (B, red bars) cohorts. In each plot, the black, grey, and white areas represent With-The-Rule (WTR, axis: 0°-30° or 150°-180°), Against-The-Rule (ATR, axis: 60°-120°), and OBLique (OBL, axis: 30°-60° or 120°-150°) astigmatism, respectively.

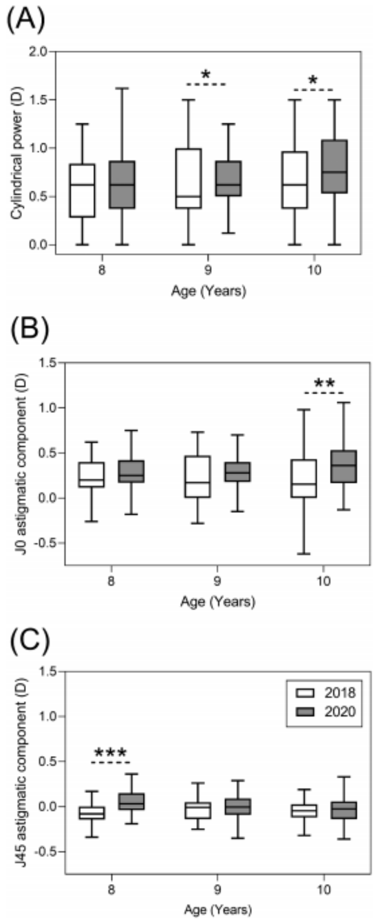

Figure 4. Comparisons of astigmatic components between the two cohorts for the three age groups. Cylindrical power (A), J0 (B) and J45 (C) astigmatic components for the two cohorts (White, 2018 cohort; Grey, 2020 cohort) are plotted as a function of age. The solid line in the box and the box margins indicate the median and interquartile range, respectively. Mann-Whitney U test: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

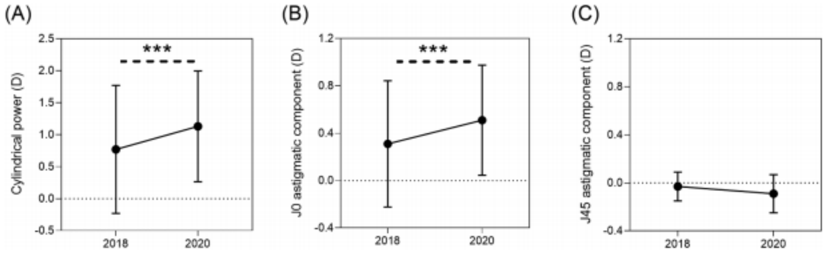

Figure 5. Longitudinal changes in astigmatic components (Mean±SD) of the 38 children who participated in both surveys. Cylindrical power (A), J0 (B) and J45 (C) astigmatic components collected in 2018 and 2020 are compared. Paired t-test: *** $p < 0.001$.