Clinical and Epidemiologic Research

COVID-19 Home Quarantine Accelerated the Progression of Myopia in Children Aged 7 to 12 Years in China

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Purpose. To investigate the effect of home quarantine during the COVID-19 pandemic on myopia progression in children and its associated factors.

Methods. Myopic children aged 7 to 12 years with regular follow-up visits every half a year from April 2019 to May 2020 were included. Cycloplegic refraction was measured at baseline and at two follow-up visits. The first follow-up visit (visit 1) was conducted before the COVID-19 home quarantine, whereas the second (visit 2) was four months after the home quarantine. Myopia progression at visits 1 and 2 were compared. Factors associated with changes in myopia progression were tested with a multiple regression analysis.

Results. In total, 201 myopic children were enrolled. There was a significantly greater change in spherical equivalent at visit 2 (-0.98 ± 0.52 D) than at visit 1 (-0.39 ± 0.58 D; $P < 0.001$). Students were reported to have spent more time on digital devices for online learning ($P < 0.001$) and less time on outdoor activities ($P < 0.001$) at visit 2 than at visit 1. Children using television and projectors had significantly less myopic shift than those using tablets and mobile phones ($P < 0.001$). More time spent on digital screens ($\beta = 0.211$, $P < 0.001$), but not less time on outdoor activities ($\beta = -0.106$, $P = 0.110$), was associated with greater myopia progression at visit 2.

Conclusions. Changes in behavior and myopic progression were found during the COVID-19 home quarantine. Myopic progression was associated with digital screen use for online learning, but not time spent on outdoor activities. The projector and television could be better choices for online learning.

Keywords: COVID-19, myopia, digital screen device, outdoor activity

Myopia has emerged as a major public health concern, especially in East and Southeast Asia, paralleled by a myopia epidemic.[1,2] Research has suggested that close to 50% of the world's population may be myopic by 2050, with as much as 10% highly myopic.[3] In China, the past few decades have already witnessed an increasingly high prevalence of myopia (80%–90% in young adults), and the consequent pathologies associated with high myopia (10%–20% in young adults).[4] This may foreshadow an increase in low vision and blindness due to pathological myopia in the future.

After the COVID-19 pandemic began, the Chinese government made great efforts to effectively manage the virus. During the pandemic, people were obliged to home quarantine, outdoor activities were forbidden for at least three months (from February to April), and students were required to study online using digital screen devices for four months (from February to May).[5] The spread of COVID-19 was effectively contained by May in China, after which the ban on outdoor activity was relaxed, and some children had a small increase in outdoor time, whereas most students continued their online learning. Digital screen devices are synonymous with near work,[6] and their use has been found to be associated with the development of myopia.[7–9] Although multiple studies on the risk factors and clinical features of COVID-19 have been conducted, the influence of the excessive use of digital screen devices on myopia caused by home quarantine has been ignored. In addition, although evidence has shown that children who spend more time outdoors have a lower incidence of myopia,[10–13] the protective effect of time spent outdoors on myopia progression remains controversial. Whether increased screen time for online learning and reduced outdoor time during the home quarantine during the COVID-19 pandemic influenced myopia progression therefore merits further investigation.

The purpose of this study was to compare myopia progression before and after COVID-19 home quarantine among students aged 7 to 12 years and to explore the associated factors that affect the rate of myopia progression.

Methods

Design and Subjects

The study adhered to the Declaration of Helsinki. Ethics approval was obtained from the local institute's ethics committee (Shanghai General Hospital). The participants understood the study protocol, and their parents/caregivers signed written informed consent.

Myopic children attending regular follow-up visits to Shanghai General Hospital during the study period April 2019 to May 2020 were enrolled in this study. The following were inclusion criteria: (1) children who agreed to receive cycloplegia; (2) spherical equivalent (SE) ≤ -0.50 D at baseline; (3) available for three visits at approximately six-month intervals over the study period. Subjects undergoing orthokeratology or multifocal contact lens wear or using atropine of any concentration during the study period and those with ocular pathology, including amblyopia, strabismus, and previous ocular surgery were excluded.

The baseline examination was conducted between April and May 2019, the first follow-up visit (visit 1) was conducted between October and November 2019, and the second follow-up visit (visit 2) was in May 2020—after 4 months of lockdown and quarantine measures in China during the COVID-19 pandemic.

Refraction Assessment and Questionnaire

Participants underwent a comprehensive examination at the clinic. Visual acuity, intraocular pressure, cycloplegic refraction, and digital fundus photography were performed. Cycloplegia was achieved by administrating one drop of topical 0.5% proparacaine hydrochloride (Alcaine; Alcon, Fort Worth, TX, USA) followed five minutes later by two drops of 1% cyclopentolate (Cyclogyl; Alcon) in each eye. The interval between each of the two drops was five minutes. Pupil size and light reflex were examined 30 minutes after the last drop, and cycloplegia was deemed complete if pupil size $\geq$6 mm and light reflex were absent. Cycloplegic refraction was measured with an autorefractor (KR-8900; Topcon, Tokyo, Japan). Three repeated measurements were taken and averaged.

The parents/caregivers of the participants were asked to complete a paper questionnaire at follow-up visits. The questionnaire collected information including the average time spent each day on learning with digital screen devices (including mobile phone, tablet, television, and projector), performing other near work (such as reading books, doing homework, or reading music scores to learn musical instruments), and participating in outdoor activities.

The details of the questions about the use of digital screen devices, other near work, and outdoor activities are shown in Table 1. The responses were collected separately for weekdays and weekends. The average daily hours spent on those activities was calculated using the following formula: [(hours spent on a weekday) $\times$ 5 + (hours spent on a weekend) $\times$ 2]/7.

At visit 2, the average time spent per day on digital screen device use and outdoor activities in each month, and information on the type of digital devices used were also collected by an additional questionnaire (details are in the Supplementary Tables S1 and S2).

Table 1. The Details of Questions in the Questionnaire About Digital Screen Device Use, Other Near Work, and Outdoor Activities

1. Which device(s) was/were chosen for your child to use for online learning between the last visit and this visit?				
Mobile phone	Tablet	Television	Projector	Others:
2. How many hours per day did the child use the device(s) for online learning between the last visit and this visit? Please fill in the blanks with a value next to the device(s) you chose.				
Mobile phone	Tablet	Television	Projector	Others
Weekdays (h/d)	Weekdays (h/d)	Weekdays (h/d)	Weekdays (h/d)	Weekdays (h/d)
Weekends (h/d)	Weekends (h/d)	Weekends (h/d)	Weekends (h/d)	Weekends (h/d)
3*. How many hours per day did the child read books, do homework or read musical scores to learn musical instruments between the last visit and this visit? Please fill in the blanks with a value next to your selection(s).				
Read books	Read musical scores	Do homework		
Weekends (h/d)	Weekdays (h/d)	Weekdays (h/d)		
Weekdays (h/d)	Weekends (h/d)	Weekends (h/d)		
4. How many hours per day did the child participate in outdoor activities between the last visit and this visit? Please fill in the blanks with a value.				
Weekdays (h/d)	Weekends (h/d)			

* The summation of the hours (read books, read musical scores and do homework) was calculated as other near work time.

Table 2. The Comparison of Myopia Progression and Associated Factors at the First and Second Visit

	Visit 1		Visit 2		
	Mean ± SD	**Range**	**Mean ± SD**	**Range**	***P* Value***
Changes in SE, D	−0.39 ± 0.58	−1.00 to 0.25	−0.98 ± 0.52	−2.00 to −0.13	<0.001
Digital screen time, hrs/d	0.67 ± 0.25	0.25 to 1.50	5.24 ± 0.75	4.08 to 6.60	<0.001
Outdoor time, hrs/d	1.11 ± 0.35	0.50 to 2.00	0.49 ± 0.23	0.25 to 2.79	<0.001
Other near work, hrs/d†	2.07 ± 0.56	1.00 to 3.00	0.97 ± 0.38	0.00 to 2.00	<0.001

SD, standard deviation.
* Statistical significance between visit 1 and visit 2 was tested using paired *t* test.
† Other near work: reading books, doing homework, and reading music score.

Statistical Analysis

Statistical analysis was performed using SPSS software (SPSS Statistics 23; IBM, Armonk, NY, USA). The more myopic eye at baseline was included as the study eye for analysis. The SE was calculated as sphere power plus half-negative cylinder power. Myopia was defined as an SE of cycloplegic refraction ≤ −0.50 D.

The parameters were presented as mean ± standard deviation for continuous variables and as rates (proportions) for the categorical data. The differences in SE between baseline and two follow-up visits were compared using repeated measures analysis of variance by testing sphericity. When the sphericity assumption was violated, the Greenhouse-Geis test was used. The Bonferroni method was used to adjust for comparisons across the post hoc tests. The comparison between visit 1 and visit 2 was tested using paired *t*-testing. Analyses of variance with post hoc tests to examine intergroup differences, that is, among four types of digital devices using Turkey for homogeneity of variance, and Dunnet T3 for heterogeneity of variance, after confirming that the data conformed to the normal distribution.

Changes in myopia progression were calculated as changes in SE during the second half-year follow-up period minus changes in SE during the first half-year follow-up period. Change in viewing habits was calculated as time spent on digital devices for online learning, near work, and outdoor activities during the second half-year follow-up period (collected at visit 2) minus that spent during the first half-year follow-up period (collected at visit 1). Correlations of changes in viewing habits and changes in myopia progression were analyzed using Pearson's correlation coefficients. Factors associated with changes in myopia progression were tested with a multiple regression analysis. *P* values <0.05 were considered statistically significant.

Results

In total, 201 myopic children were included, with a mean age of 9.9 ± 1.7 (range, 7.0–12.0) years at baseline, and 48% were boys. The average interval between baseline and visit 1, and between visit 1 and visit 2, was 5.7 ± 0.5 months and 5.4 ± 0.5 months, respectively.

At baseline examination, the mean SE was −1.86 ± 0.76 D, ranging from −0.63 to −4.25 D. All participants enrolled in our study had sphere power ≤ −0.5 D, that is, no child with astigmatism only was misclassified as having myopia. During the 1-year follow-up period, SE decreased significantly ($P < 0.001$), with mean SE of −2.25 ± 0.75 D and −3.23 ± 0.65 D at visit 1 and visit 2, respectively. As shown in Table 2, there was a significantly greater change in SE at visit 2 than visit 1 ($P < 0.001$), with an average myopic shift of −0.39 ± 0.58 D and −0.98 ± 0.52 D at visit 1 and visit 2, respectively.

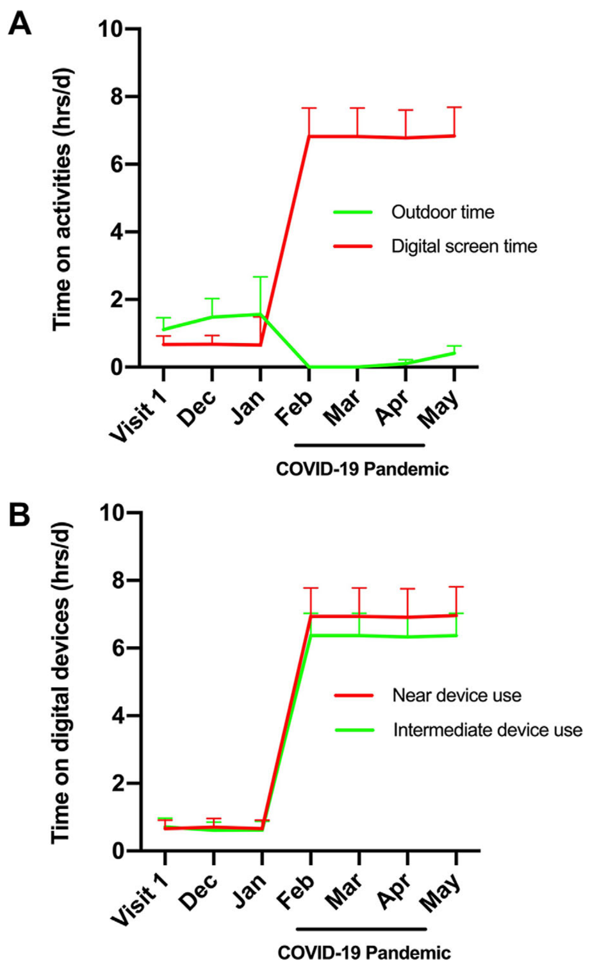

Figure. (**A**) Time spent on digital devices for online learning and on outdoor activities during the COVID-19 pandemic. (**B**) Time spent on near and intermediate digital device use. Near device use included mobile phone and tablet use, whereas intermediate device use included television and projector use. Time spent between December 2019 and May 2020 was reported at visit 2. Mean and standard deviation are presented for each month.

During the first half-year period, greater myopia progression was associated with less outdoor time ($r = 0.401$, $P < 0.001$), more near work ($r = -0.394$, $P < 0.001$), and more digital screen time for online learning ($r = -0.244$, $P < 0.001$). During the second half-year period, greater myopia progression was significantly correlated to more digital

Table 3. The Comparison of Myopia Progression and Associated Factors Among Participants Using Different Types of Digital Devices at Visit 2*

	Mobile Phone	Tablet	Television	Projector	*P* Value
No.	19	139	17	26	
Age, y	9.2 ± 1.5	9.8 ± 1.7	10.0 ± 1.3	10.4 ± 1.9	0.094†
Gender, % of boys	68.4	46.8	41.2	46.2	0.307‡
Changes in SE, D	−1.63 ± 0.20	−1.00 ± 0.29	−0.69 ± 0.25	−0.61 ± 0.27	<0.001†
Digital screen time, h/d	5.76 ± 0.89	5.28 ± 0.74	4.80 ± 0.55	4.90 ± 0.48	<0.001†
Outdoor time, h/d	0.50 ± 0.17	0.50 ± 0.26	0.43 ± 0.07	0.46 ± 0.18	0.576†
Other near work, h/d§	1.08 ± 0.38	0.95 ± 0.38	0.97 ± 0.37	0.98 ± 0.39	0.576†

* Mean ± standard deviation was presented except where noted otherwise.
† Statistical significance among different types of digital devices was tested using variance analysis.
‡ Statistical significance was tested using χ^2 tests.
§ Other near work: reading books, doing homework, and reading music score.

Table 4. Multiple Regression Analysis of Factors Associated With Changes in Myopia Progression

				Collinearity Statistics	
	Estimate (95% CI)	Standard Error	*P* Value	Tolerance	VIF†
Intercept	−0.306 (−0.769 to 0.157)	0.235	0.194		
Age, y	0.069 (0.036 to 0.102)	0.017	<0.001	0.954	1.048
Gender, boys vs girls	−0.032 (−0.140 to 0.076)	0.055	0.556	0.997	1.003
Change in digital screen time, h/d	−0.211 (−0.280 to −0.142)	0.035	<0.001	0.977	1.023
Change in outdoor time, h/d	0.106 (−0.024 to 0.236)	0.066	0.11	0.982	1.019
Change in other near work time*, h/d	−0.068 (−0.168 to 0.031)	0.051	0.179	0.953	1.05

CI, confidence interval; VIF, variance inflation factor.
* Other near work: reading books, doing homework, and reading music score.
† VIF less than five is commonly regarded as the absence of collinearity.

screen time for online learning ($r = -0.360$, $P < 0.001$), whereas no such correlation was observed for outdoor time ($r = -0.026$, $P = 0.713$) and near work ($r = 0.068$, $P = 0.334$).

When compared with visit 1, parents/caregivers reported that children spent significantly more time on digital devices for online learning each day at visit 2 (visit 1: 0.67 ± 0.25 h/d, visit 2: 5.24 ± 0.75 h/d; $P < 0.001$), and significantly less time on outdoor activities (visit 1: 1.11 ± 0.35 h/d, visit 2: 0.49 ± 0.23 h/d; $P < 0.001$) and on other near work (visit 1: 2.07 ± 0.56 h/d, visit 2: 0.97 ± 0.38 h/d; $P < 0.001$) at visit 2 (Table 2). As illustrated in the Figure, online learning digital screen time increased, whereas outdoor time decreased drastically from February 2020 when lockdown and quarantine measures were strictly imposed in most cities in China because of the COVID-19 pandemic.

A significant difference in change of SE during the second half-year follow-up period was found between different types of digital devices used (mobile phone: −1.63 ± 0.20 D; tablet: −1.00 ± 0.29 D; television: −0.69 ± 0.25 D; projector: −0.61 ± 0.27 D; $P < 0.001$; Table 3). Children using televisions and projectors had significantly less myopic shift than those using tablets ($P < 0.001$), who had slower myopia progression than those using mobile phones ($P < 0.001$); however, no statistically significant differences in change to SE were observed between children using television and those using projector ($P = 0.785$).

More time spent on digital devices for online learning and doing other near work was significantly correlated to faster myopia progression ($r = -0.383$, $P < 0.001$ for digital screen time; $r = -0.172$, $P = 0.015$ for other near work), whereas the association of outdoor time with myopia progression was borderline significant ($r = 0.138$, $P = 0.050$) over visit 2 and visit 1 (5.4 months) than visit 1 and baseline (5.7 months). In the multiple regression analysis, only baseline age and change in online learning digital screen time were independently related to changes in myopia progression after adjusting for related factors, with a determinant coefficient (R^2) of 0.248. According to the model, older age was a protective factor whereas more digital screen time was a risk factor (age: $\beta = 0.069$, $P < 0.001$; online learning digital screen time: $\beta = -0.211$, $P < 0.001$, Table 4), with an increase of 1 h/d spent on digital devices for online learning corresponding to a myopia progression of 0.21 D.

There were two children with SE showing a hyperopic shift at visit 1, with SE changes of +0.13 D and +0.25 D, respectively. The above analysis was completed after excluding the two cases, with no change in the results found and thus no change in the conclusions.

Discussion

To our knowledge, this is the first study showing associated factors that affected the rapid progression in myopia in 7- to 12-year-old students during the home quarantine period during the COVID-19 pandemic. The increase in myopia from visit 1 to visit 2 (−0.98 ± 0.52 D, 5.4 months) was nearly three times greater than that from baseline to visit 1 (−0.39 ± 0.58 D, 5.7 months). An association between increased time of digital screen device use for online learning during home quarantine and rapid progression of myopia was found in this research. Myopia progression in students using projectors and television was found to be slower than in those using mobile phones and tablets. Although outdoor time decreased significantly during the home quarantine period, there was no association between decreased outdoor time and myopia progression.

Myopia incidence and progression in children have been shown to vary significantly across different ethnicities, ages, and regions. In a Singapore study, myopia progression was 0.8 D/y in children aged 7 to 9 years.[14] In a European study, the progression was almost 1.2 D/y aged 5 to 14 years.[15] Myopia progression in China also varies in different regions, because China is a large country with imbalances in the development of the regional economy and education across different areas. In a recent Beijing study that enrolled 220 children aged 6 to 12 years, myopia progression was 0.76 D/y.[16] In a study conducted in Chongqing (Western China), progression was 0.43 D/y in children aged 6 to 15 years.[17] In Hong Kong, progression was found to be 0.63 D/y in children aged 5 to 16 years.[18] In this study (carried out in Shanghai), we found that myopia progression was about −0.78 D/y (−0.39 ± 0.58 D/half-year) at visit 1. Our results were similar to the latest study from Beijing.[16] Although myopia progression at visit 1 was high, it also accelerated significantly at visit 2 in our study, with an average progression of about 1.96 D/y (−0.98 ± 0.52 D/half-year). This was far greater than at visit 1 and previously reported rates in China,[16–18] indicating the impact of the home quarantine caused by COVID-19 on myopia progression, at least for students aged 7 to 12 years.

We observed that an average of 0.67 h/d was spent on digital screen devices for online learning before the COVID-19 pandemic. This was in accordance with the time recommended by the Chinese government, that is, that digital screen devices should be used for less than 1 h/d to control myopia. During the home quarantine period, schools were closed, and school-aged children were required to study online,[5] which inevitably led to the excessive use of digital screen devices. Screen time for online learning increased significantly, reaching an average of 5.24 h/d at visit 2, nearly 10 times longer than before. Furthermore, the results of the multiple regression analysis suggested that increased digital screen time for online learning was independently associated with accelerated myopia progression during the home quarantine. Recent studies have also found that myopic children spent more time on computer and video games than nonmyopic ones[8,19] and that overuse of screen devices was linked with increased myopia prevalence, especially when using devices for more than 3 h/d.[7,8]

Myopia progression in students using projectors and televisions for online learning was found to be slower than those using mobile phones and tablets. This result was consistent with previous studies demonstrating a strong association between myopia and the use of computer and mobile phones, but a relatively weaker correlation with the use of television.[7,8,19–22] Two underlying mechanisms have received some speculation. First, the distance between projector and television screens and the eyes is usually greater than 1 m, but the distance is always less than 50 cm when using mobile phones or tablets because of the small font size.[23,24] Shorter viewing distances, which would have required increased accommodation effort, were demonstrated to be associated with more myopia progression.[4,8] Salmeron-Campillo et al.[25] found that when using tablets, a shorter distance between eye and screen (36.8 ± 5.7 cm) needed more than 0.6 D accommodation, compared with a distance of 47.2 ± 6.5 cm. In addition to the viewing distance, students tend to spend more time on tablets (0.5 h/d higher) and mobile phones (1 h/d higher), as seen in our results (Table 3). This was possibly related to the fact that students also tend to spend more time on recreational applications (apps) such as video and games when using mobile phones for online learning, although the exact number of apps in different gadgets was not compared in previous studies. Above all, it is suggested that projectors and televisions are more suitable choices for the prevention of myopia progression, when online learning is inevitable. Recommendations by ophthalmologists in recent years for reductions in the use of smart phones to slow myopia progression[26] are also supported by these findings.

Although increased outdoor time is considered to reduce the incidence of myopia,[10,11] the protective role of outdoor activity in preventing myopia progression has been disputed.[12,27,28] Outdoor time during the home quarantine period significantly decreased from an average of 1.11 h/d to 0.49 h/d; however, no association between reduced outdoor time and faster myopia progression was observed. This might be because outdoor time was still less than 2 h/d before the home quarantine, which is under the threshold required to have a positive effect, or be due to the different influence of outdoor activities on myopia onset and its progression, with no protective effect in children who are already myopic.

Certain limitations in our study should be recognized. First, this was a single-center study with a small sample; thus the generalization of the results might be limited to regions with similar situations in terms of myopia. There were no age-specific data on behavior changes and myopia progression for our small sample. Furthermore, multicenter and large-sample research would be helpful to our understanding of the overall impact of the COVID-19 home quarantine on myopia progression. Second, the influence of other factors, such as seasonal differences in myopia progression, could not be determined. Some studies have found that the progression of myopia in winter is faster than in summer.[29–31] Donovan et al.[31] found that myopia progression varied seasonally in Chinese children aged 6 to 12 years, with the mean 6-month progression being −0.31 ± 0.25 D in summer, −0.40 ± 0.27 D in autumn, −0.53 ± 0.29 D in winter, and −0.42 ± 0.20 D in spring. After estimating these dates with annualized equivalents, the progression in summer and autumn was about 0.71 D/y, which was similar to our study at visit 1, covering summer and autumn. However, the progression in winter and spring was about 0.96 D/y, which was less than that during the home quarantine period (covering winter and spring) of our study (1.96 D/y). Therefore the impact of seasonal factors may only partly account for the changes, and the influence of home quarantine appeared to have played a more important role. Third, to collect a comprehensive breakdown of the time spent on different activities for each of the months during the COVID-19 outbreak, which might have affected the potential biases. Finally, our questionnaire did not cover devices used for online learning in school, the distance between the eyes and the screen, details on breaks in using screen devices, or digital screen device use for playing games. The influence of these factors on myopia progression needs further investigation.

In summary, we found an accelerated progression of myopia because of the excessive use of digital screen devices for online learning during the home quarantine caused by the COVID-19 pandemic. We suggest that using a projector or television could be better choices for online learning than mobile phones and tablets in preventing myopia progression. This study will help us to understand better myopia progression under the background of home quarantine during the COVID-19 pandemic and will provide new insights into the control of myopia in future practice.

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