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ORIGINAL RESEARCH

Changes in Refractive Error Under COVID-19: A 3-Year Follow-up Study

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ABSTRACT

Introduction: To investigate changes in refractive error in schoolchildren before and during the coronavirus disease 2019 (COVID-19) pandemic.

Methods: This study included 2792 students, who underwent a 3-year follow-up from 2018 to 2020. All participants underwent yearly noncycloplegic refraction and ocular examinations. Time-related changes in sphere, cylinder, and spherical equivalent (SE) measurements in both genders were analyzed.

Results: The myopic sphere (− 0.78 ± 1.83 vs. − 1.03 ± 1.91 D; $P = 0.025$) and SE (− 1.04 ± 1.90 vs. − 1.32 ± 1.99 D; $P = 0.015$) progressed significantly from 2018 to 2019. Female participants had a significantly greater change in SE than male participants ($P < 0.05$), and the low hyperopia, emmetropia, and mild myopia groups significantly deteriorated ($P < 0.001$) from 2018 to 2019. Significant differences in sphere change (− 0.21 ± 0.97 vs. − 0.36 ± 0.96 D; $P < 0.001$) and SE change (− 0.23 ± 0.99 vs. − 0.38 ± 0.98 D; $P < 0.001$) were noted between 2019–2018 and 2020–2019, respectively. The respective changes in cylinder were statistically similar (− 0.03 ± 0.53 vs. − 0.05 ± 0.62 D; $P = 0.400$).

Conclusions: The refractive status of schoolchildren showed an increasing myopic shift trend before and during the COVID-19 pandemic. The low hyperopia, emmetropia, and mild myopia groups were more sensitive to environmental changes during COVID-19 than before. The myopic shift was greater in female participants than male participants.

Keywords: Refractive error; COVID-19; Myopia; Hyperopia; Emmetropia

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Key Summary Points

Why carry out this study?

The description of refraction changes during the past 3 years in the coronavirus disease (COVID-19) pandemic has rarely been reported.

What was learned from the study?

The refractive status of schoolchildren showed an increasing myopic shift trend before and during the COVID-19 pandemic.

The low hyperopia, emmetropia, and mild myopia groups were more sensitive to environmental changes during COVID-19 than before.

A shifting trend towards an increase in myopia progression was greater in female participants than male participants.

INTRODUCTION

The worldwide COVID-19 outbreak and spread have posed a great threat to global public health [1, 2]. Strict domestic and foreign restrictions implemented on social interactions have introduced new ways of studying and living to children. Their severely limited outdoor time may result in reduced exposure to sunlight, limited far vision exercises, and increased online learning and digital screen time [3–5]. The myopia burden has become a burgeoning global public health concern, especially amid this unprecedented pandemic [6, 7]. Xu et al. and Ma et al. reported that COVID-19-induced myopia development in students should be addressed and controlled [8, 9]. However, big data are lacking, and much remains uncertain concerning the concrete subgroups of refractive error (RE) changes and gender disparity occurring in schoolchildren during this particular period. It is of utmost importance to understand the details and investigate possible gender disparity for improved post-COVID-19 pandemic myopia control and ophthalmic care. This cohort study assessed the changes in RE in schoolchildren during 2018–2020.

METHODS

Subjects

This population-based cohort study longitudinally investigated childhood RE development in Tianjin, China (Trial registration NCT05119543). The current study included 2792 students with a 36-month follow-up from 2018 to 2020.

In addition to RE considerations, the inclusion criteria were no concurrent eye disease; age 6–18 years. The exclusion criteria were significant systemic illnesses or ocular conditions that could affect the corneal curvature, including congenital corneal diseases, pterygium, keratoconus, other corneal degeneration or dystrophy conditions, media opacity, uveitis, glaucoma or a history of intraocular surgery, refractive surgery, neurologic or retinal diseases, current corneal refractive therapy (ortho-K), or low-dose atropine therapy for myopia control. The ethics board of the Tianjin Eye Hospital, Tianjin, China, approved this school-based cohort study (No. 2021022), which adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from all participants and their parents or legal guardians. Oral assent was obtained from all children before each examination.

Examinations and Assessments

Noncycloplegic refraction was measured at yearly follow-up screenings. Participants comprised Chinese primary to high school students in Tianjin (grades 1–13, aged 6–18 years). The participants underwent a full ophthalmic examination, including visual acuity assessment, anterior segment examination with a slit lamp, fundus examination with a direct ophthalmoscope, and refraction assessment by autorefractometer. Students were asked to remove their glasses before the examination. Noncycloplegic refraction measurement was performed annually using a Tianle RM9000 autorefractometer (Ningbo Ming Sing Optical R&D Co, Ltd, Zhejiang, China). Three valid consecutive refraction readings in a normal environment were obtained, and their mean was used as the mean spherical equivalent (SE) for statistical analysis.

Definitions

SE was defined as the spherical power plus half the cylindrical power. Myopia was identified as SE ≤ -0.5 diopters (D) [10]. We divided the RE into six groups: high hyperopia (SE $> +2.00$ D); low hyperopia ($+0.50$ D $\leq$ SE $\leq +2.00$ D); emmetropia (-0.50 D $<$ SE $< +0.50$ D); mild myopia (-3.0 D $\leq$ SE ≤ -0.50 D); moderate myopia (-5.00 D $<$ SE < -3.00 D); and high myopia (SE ≤ -5.00 D) [10].

Data Analysis

Data were analyzed using the mgcv package of R software, version 3.6.2 (R Inc., Chicago, IL, USA), and figures were generated using RStudio, version 1.3.1056 (RStudio PBC). The generalized estimation equation was used to determine the associations between the annual increase in myopia and the grade, gender, and RE type. All statistical tests were unpaired, two-sided, and the statistical significance was set at $P < 0.05$. The refraction distribution and RE changes through follow-up were tested using a generalized linear mixed model. The refraction distribution was considered normal when $P > 0.5$. The six refraction types were compared in the different years using the analysis of variance with the Bonferroni post hoc test and *t* test for pairwise comparisons. Values are presented as means ± standard deviations or numbers with percentages. Groups were compared using *t* test or chi-squared test as appropriate. Changes in myopia between follow-up examinations were calculated. Only the right eye (OD) values were used for statistical analyses, since the eyes were highly correlated.

Table 1 Refraction distribution in the 3-year follow-up

Refraction	2018		2019		2020	
	N	%	*N*	%	*N*	%
High hyperopia	18	0.64	20	0.72	17	0.61
Low hyperopia	1507	53.98	1331	47.67	1104	39.54
Emmetropia	112	4.01	124	4.44	119	4.26
Mild myopia	846	30.30	969	34.71	1068	38.25
Moderate myopia	208	7.45	205	7.34	316	11.32
High myopia	101	3.62	143	5.12	168	6.02

RESULTS

The study included 2792 students of grades 1–12, 1495 of which (53.6%) were male. The participants' refraction details are presented in Table 1. The sphere and SE, but not the cylinder, showed a myopic shift from 2018 to 2020 in both genders in grades 1–4, 7, and 10. Significant grade-related effects on sphere were noted in grades 1–7 ($P < 0.001$), but not in grade 10 ($P = 0.12$). Significant grade-related effects on cylinder were noted in grades 3, 4, and 7 ($P < 0.05$), but not in grades 1, 2, and 10 ($P > 0.05$). Significant grade-related effects on SE were noted in grades 1–4 and 7 ($P < 0.001$), but not in grade 10 ($P = 0.091$).

Significant changes in sphere were noted in the low hyperopia and mild myopia subgroups ($P < 0.05$ for all), but not in the other subgroups ($P > 0.05$; Fig. 1). Furthermore, we found a significant myopic change in SE in the low hyperopia, emmetropia, and mild myopia subgroups ($P < 0.001$), but not in the other subgroups ($P > 0.05$; Fig. 2).

Significant differences were found in the sphere and SE when the genders and years were compared (Figs. 3, 4). The mean SE differed significantly in three subgroups (low hyperopia, emmetropia, and mild myopia) between male

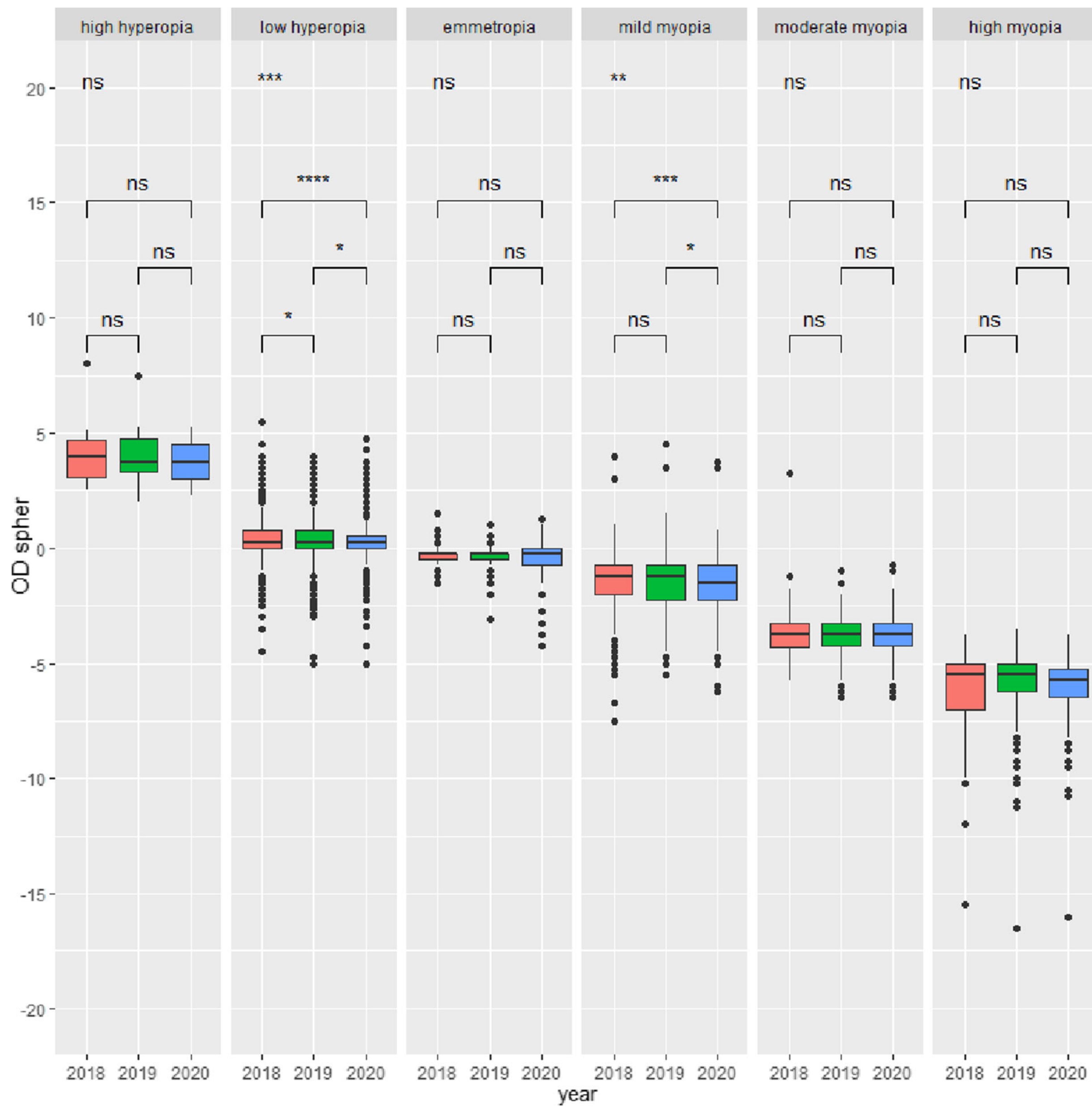

Fig. 1 Box plot of OD sphere change in the different ametropia ($P < 0.001$***, $P < 0.01$**, $P < 0.05$*, *ns* not statistically significant)

participants and female participants ($P < 0.001$).

The change in sphere differed significantly between male participants and female participants for 2018 vs. 2019 (– 0.78 ± 1.83 vs. – 1.03 ± 1.91 D, respectively; $P = 0.025$) but not for 2019 vs. 2020 (– 1.03 ± 1.91 vs. – 1.42 ± 2.00 D, respectively; $P > 0.05$; Tables 1 and 2). The change in SE in 2019 (– 1.32 ± 1.99 D) was significantly greater than in 2018 (– 1.04 ± 1.90 D; $P = 0.015$), while the changes in 2019 and 2020 were similar (– 1.32 ± 1.99 vs. – 1.72 ± 2.09 D, respectively; $P > 0.05$; Table 2). The change in myopic

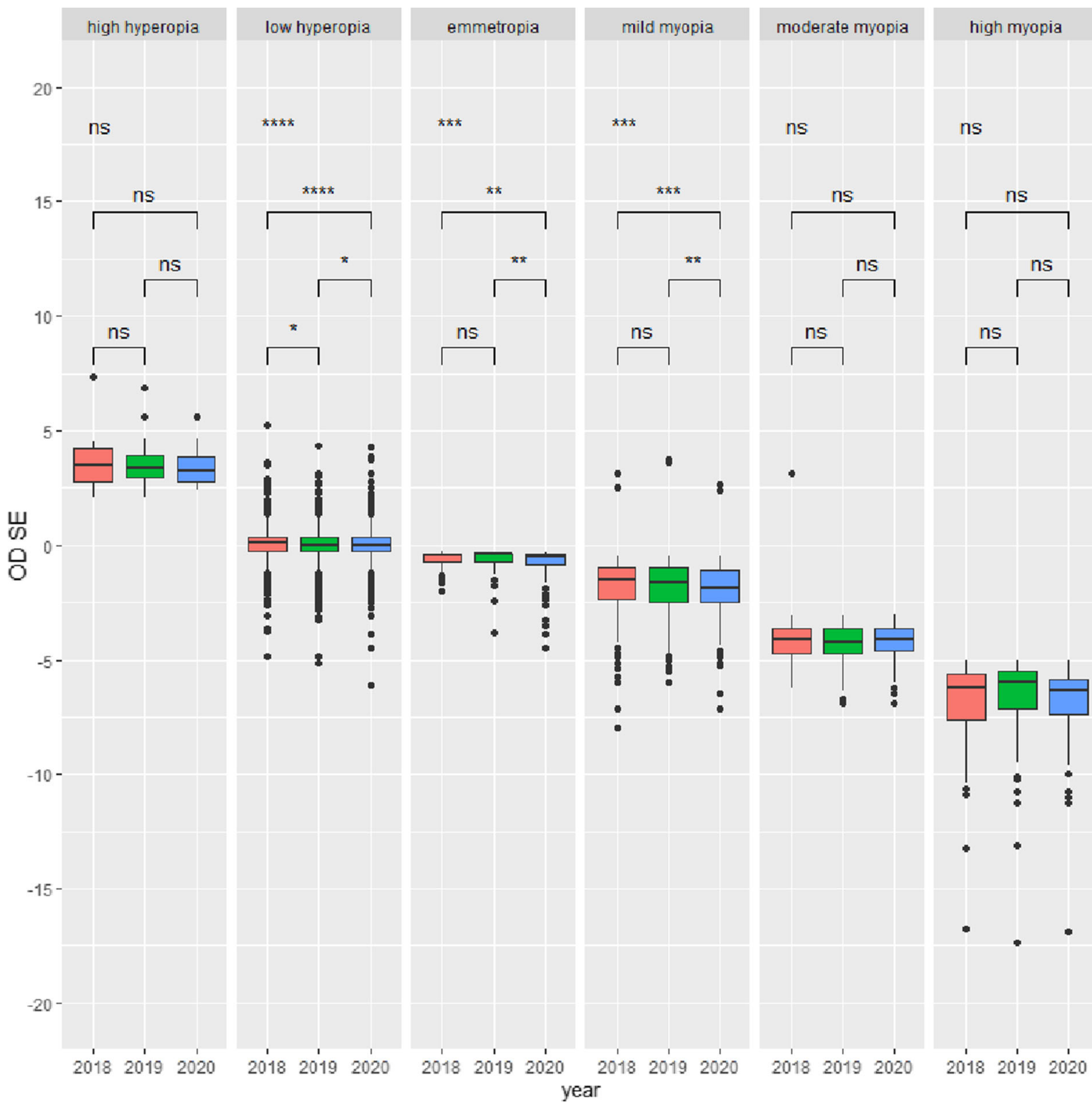

Fig. 2 Box plot of OD SE change in the different ametropia ($P < 0.001$***, $P < 0.01$**, $P < 0.05$*, *ns* not statistically significant)

shift between 2019 and 2020 was greater than between 2018 and 2019 in sphere (− 0.36 ± 0.96 vs. − 0.21 ± 0.97 D, respectively; $P < 0.001$) and SE (− 0.38 ± 0.98 vs. − 0.23 ± 0.99 D, respectively; $P < 0.001$), but not in the respective values for cylinder (− 0.05 ± 0.62 and − 0.03 ± 0.53 D, respectively; $P = 0.400$).

DISCUSSION

Notably, this study was the first to identify significant sphere myopic shifts in low hyperopia and mild myopia, and SE myopic shifts in the low hyperopia, emmetropia, and mild myopia groups. These were revealed to be more sensitive to environmental changes from the pre-outbreak to the COVID-19 outbreak period. We

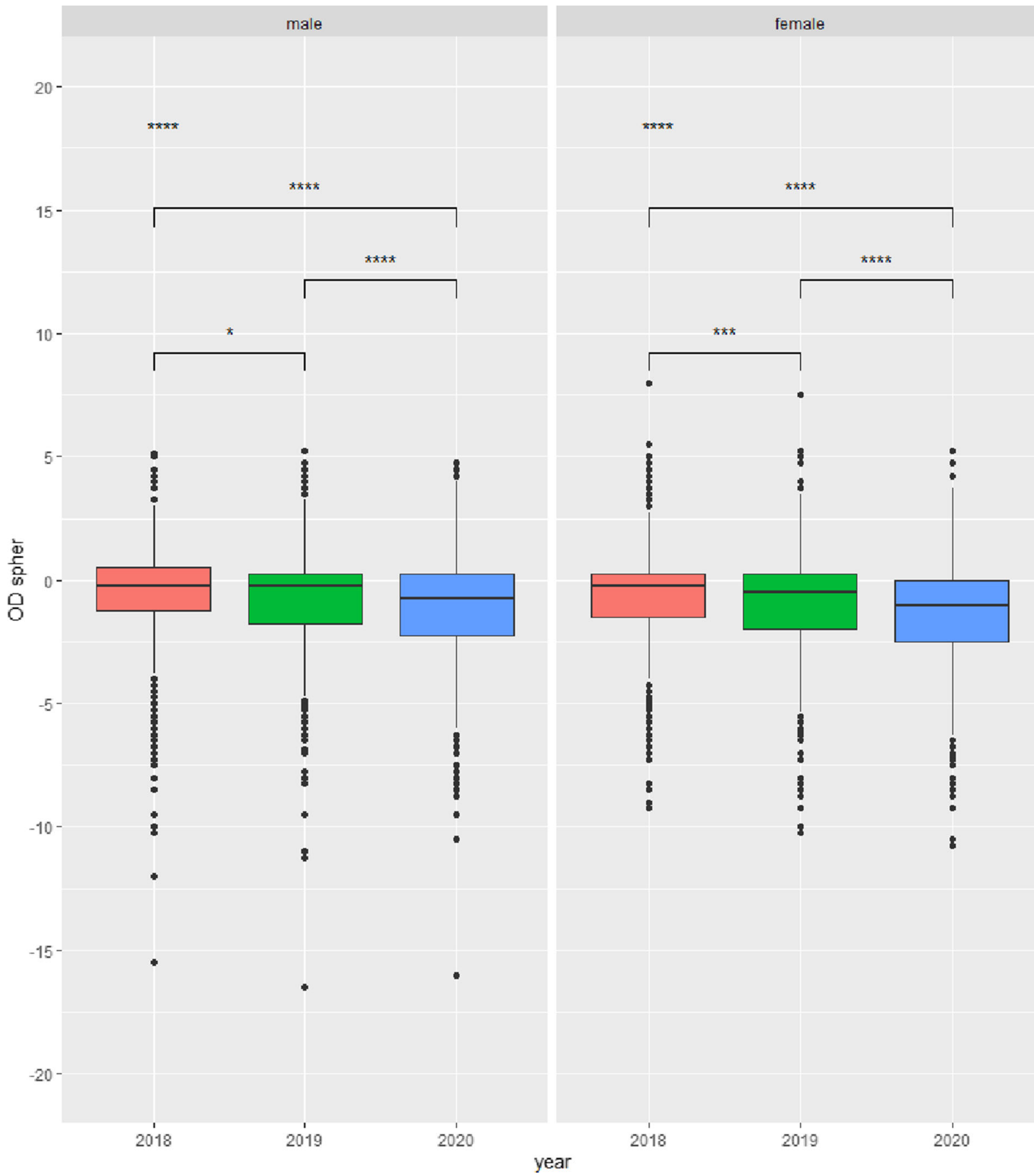

Fig. 3 Box plot of OD sphere change in the different genders and years ($P < 0.001$***, $P < 0.05$*)

also first identified that female participants had a significantly larger myopic shift than male participants during the study period. Our investigation further revealed significant changes in various ametropia subgroups in the 6–18-year-old schoolchildren cohort during the COVID-19. We evaluated refraction changes by comparing the sphere, SE, and cylinder to provide detailed insights and important data on refraction development and myopia

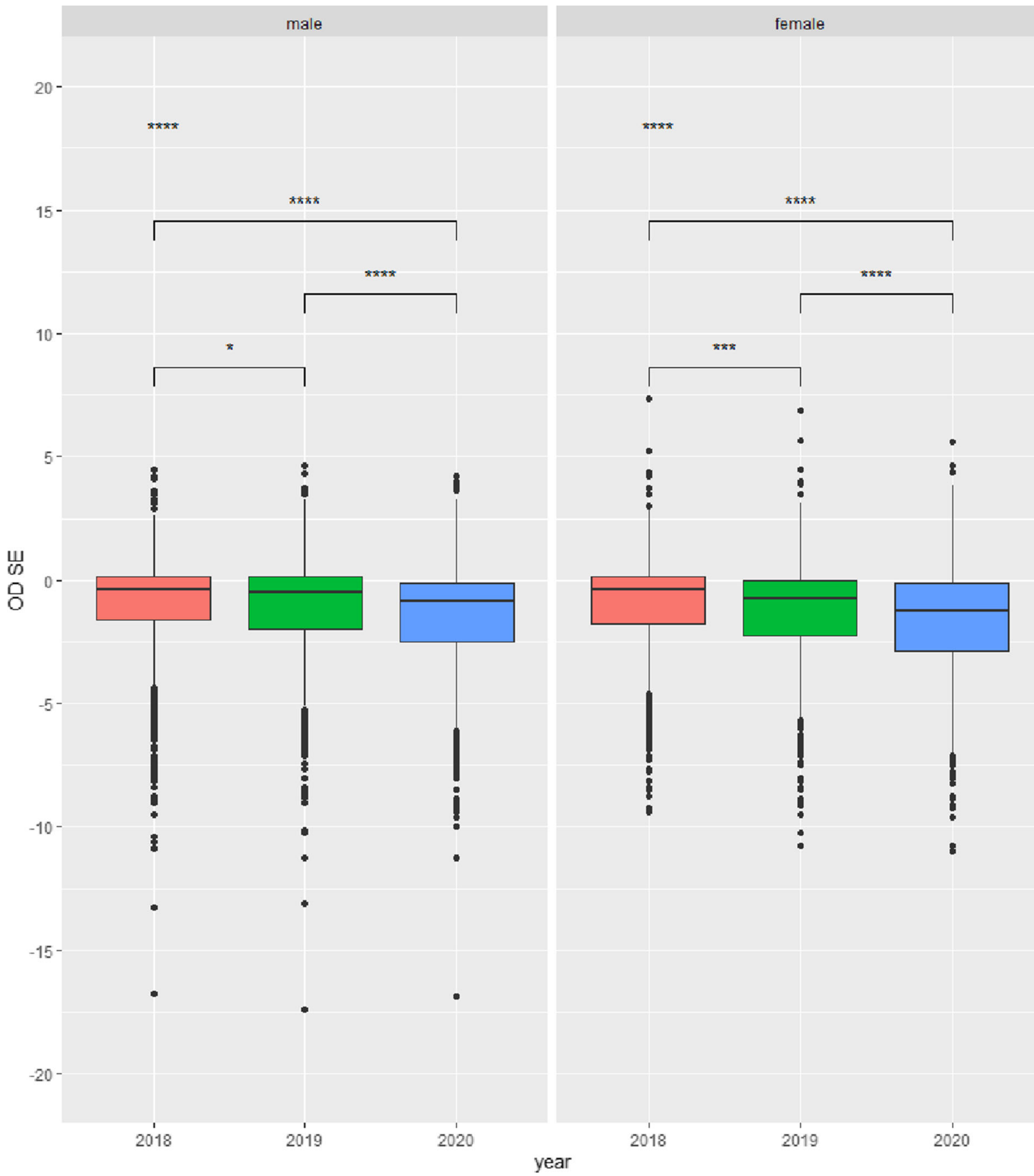

Fig. 4 Box chart of OD SE change in the different genders and years ($P < 0.0001$****, $P < 0.001$***, $P < 0.05$*)

progression from the pre-outbreak to the COVID-19 outbreak period. Another research focus of our study was a continuous 3-year follow-up of the same 2792 participants from 2018 to 2020.

Myopia has become an epidemic-like public health issue due to its soaring rates and long-term associations with sight-threatening ocular complications. The prevalence of myopia has markedly increased in East and Southeast Asia.

Table 2 Mean ± SD and median of different types of refraction and gender in different timelines

	Male			Female			*P* value
	Median	Mean	SD	Median	Mean	SD	
Sphere							
2019–2018	− 0.25	− 0.17	1.00	− 0.25	− 0.26	0.94	0.03†
2020–2019	− 0.25	− 0.34	0.99	− 0.45	− 0.39	0.91	0.16†
SE							
2019–2018	− 0.19	− 0.19	1.02	− 0.25	− 0.28	0.97	0.02†
2020–2019	− 0.38	− 0.37	1.01	− 0.38	− 0.41	0.95	0.28†

*Mean ± standard deviation (SD) was presented except where noted otherwise
†Statistical significance was tested using *t* tests

Predictions suggest that 50% of the global population will be myopic by 2050 [11]. Complications related to myopia are a major cause of visual impairment, including cataracts, glaucoma, and chorioretinal and optic disc abnormalities [11, 12]. However, early-onset myopia in children has become a leading public health concern during the past decades [13] and is an important factor leading to high myopia development [14]. Several studies during the COVID-19 outbreak showed that home confinement worsened the burden of myopia in Chinese school-aged children [6, 8, 9, 15, 16]. Therefore, it is pivotal to evaluate the concrete refraction changes associated with myopia development and devise strategies to prevent its progression and complications early in schoolchildren.

Strikingly, this study revealed significant myopic shifts in SE in the low hyperopia, emmetropia, and mild myopia subgroups from before the COVID-19 outbreak. Students with low hyperopia in 2018 had emmetropia in 2019, and students without myopia in 2019 had myopia in 2020, in agreement with the results reported by Hu et al. [17]. Few studies have provided detailed information regarding myopia progression by refraction subgroups. The increasing incidence of myopia in schoolchildren over recent decades could result from gene–environment interactions. Early myopia onset at school age could lead to faster myopia progression and greater risk of high myopia later in life than late-onset myopia [18]. Zadnik et al. found that future myopia could be predicted in nonmyopic children using an RE measure. Children with low hyperopia are at risk and should be targeted [19]. The present study showed that schoolchildren with early myopia onset were likely to have slight but significant progression, in agreement with previous studies [17, 18]. Alternatively, a previous study suggested that myopic eyes have higher RE susceptibility and progression due to near work [19]. Following this proposal, transient myopia would act like the addition of a low-powered plus lens that would reduce the accommodative stimulus, accommodative response, and correlated accommodative steady-state error. Several studies showed that myopia progression accelerated before myopia onset and continued to progress after myopic refraction was established, albeit at a slower rate. Lin et al. found that near work-induced transient myopia was significantly associated with myopic refractive shift progression among patients affected with hyperopia [20]. Several studies found less stable accommodative responses in uncorrected hyperopia, revealing the efforts of the sensorimotor system to achieve optimal response in a hyperopic eye [21, 22]. A previous study found that low and moderate levels of hyperopia positively impact the accommodative performance during sustained near activity in some schoolchildren.

Studies about gender disparity in myopia progression during the COVID-19 outbreak are rare. Our findings of larger myopic shifts in sphere and SE from 2019 to 2020 than from 2018 to 2019 in female participants than in male participants, but no shift differences in cylinder are new. Previous studies on gender differences showed mixed results. Lv and Zhang reported a significantly greater myopic shift in female participants than male participants in China [23]. Krause et al. reported that after the age of 5, myopia progression in boys was more rapid than in girls, up to the age of 15 [24]. Two underlying mechanisms could be speculated. First, good obedience to behavioral change and acceptance of online learning in female participants may have contributed to fast myopia progression during home confinement under the COVID-19 situation. Second, the female hormone peak is earlier than the male hormone peak during adolescence. It was reported that puberty in girls commenced 1.5–2 years earlier than in boys [25]. This area merits further investigation as it may improve the understanding of myopia onset and progression, especially during the COVID-19 pandemic.

This study showed that myopia progression in children varied significantly across grades and genders. Sphere and SE changes showed significant myopic shifts from grade 1 to 4 and grade 7. The grade 4 myopia shift amplitudes from 2019 to 2020 in sphere and SE were higher than in the other grades. A 5.4-month mean SE of -0.98 ± 0.52 D was reported in 208 school students in Shanghai [9]. Our results found a 12-month SE progression of -0.38 ± 0.98 D during the pandemic, slower than a previous study showing a 7-month myopia progression of -0.93 ± 0.65 D in Beijing [16]. Some other studies reported higher SE progression [9]. Our findings agreed with the cycloplegic data from Guangzhou, where a 12-month spherical equivalent refraction myopic shift of -0.35 D was found in grade 3 students [17]. The myopic shift extent in the current study also matched the noncycloplegic findings of another large-scale study in Shandong during the pandemic [6]. Some of the variations may be due to geographic or outdoor time differences before myopia onset, consistent with similar discrepancies reported by Wang et al. [6]. It was difficult to directly compare our results and those of other studies because of differences in follow-up duration, myopia definition, investigation starting time-point, and sampling methodology. The myopia shift variations in previous studies in China during the COVID-19 outbreak could also be due to differences in the regional economy, educational level, and sample size limitations [6, 8, 9, 15, 16].

The unprecedented pandemic brought dramatic changes to students' lifestyles. The online learning mode, games, storybooks, entertainment videos, and less outdoor time, among others, constituted the major forced adaptation to digital over face-to-face teaching methods and limited relaxation of regulation during home confinement [4]. Web-based learning became the most convenient and effective way for students to gain new knowledge and ensure their learning progress while at home [3, 26]. Based on a recent survey, the incidence of myopia was 45.8% in students who took online classes for less than 1 h a day, and 76.7% for those who took online classes for over 4 h daily during the pandemic [27]. The online learning time by visual display terminals was in some cases as high as 12 h a day [28]. Choosing online learning on mobile phones or tablets, prolonged digital device usage, near work, low outdoor time, and insufficient illumination are all environmental factors that played important roles in myopia development. Ma et al. revealed that myopia progression was related to the duration of online learning and digital screen time during the COVID-19 outbreak [16].

Wang et al. investigated myopia prevalence in the 6–8-year age group during the COVID-19 outbreak and found that it was 21.5% at the age of 6, 26.2% at the age of 7, and 37.2% at the age of 8 [6]. The potential mechanism of myopia progression during the pandemic could be visual fatigue caused by accommodative dysfunctions. Devices with a small screen, such as iPads and smartphones, usually used in digital teaching, tend to display crowded fonts and reduced row spacing while offering limited display brightness; this generated the need for increased eye accommodation and radial movement [29–31]. Considering that these changes might persist beyond the pandemic period [5], the accommodative dysfunctions heightened the risk of a prolonged and accelerated myopia progression.

A few limitations of this study included a regional bias caused by limiting the screening area to Tianjin. Although noncycloplegic refraction examinations did not facilitate the acquisition of cycloplegic refraction, they were useful for effective analysis and interpretation for large-scale population screening and had good consistency with cycloplegic data trends [6]. Despite the consensus that age is the main factor determining the degree of myopia shift, in some instances, it may not be the sole explanation. Other environmental and systemic factors, and their interactions, affect the progression of myopia and are worth studying in the age of COVID-19.

CONCLUSIONS

The current study provided not only new evidence of myopic shift refraction changes in schoolchildren during the COVID-19 outbreak but also confirmed many well-described patterns, including a positive myopic shift in lower-grade students and female participants. The low hyperopia, emmetropia, and mild myopia groups were more sensitive to environmental changes during COVID-19 than before. We have demonstrated how leveraging a school-based vision program could identify children at a higher risk of having a clinically significant myopic shift in their RE. These results should alert eye care professionals to make low hyperopia, emmetropia, and mild myopia a prevention and observation priority. This study reminds us of the importance of key refraction groups for myopia prevention and control. The ongoing impact of environmental changes during and beyond the COVID-19 outbreak deserves further observation with a long follow-up.

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Authorship. All named authors meet the International Committee of Medical Journal Editors (ICMJE) criteria for authorship for this article, take responsibility for the integrity of the work as a whole, and have given their approval for this version to be published.

Author Contributions. All authors contributed to the study conception, data collection, and material preparation. Xiaoyan Yang, Qian Fan, and Yue Zhang performed the data analysis and interpretation. All authors commented on previous versions of the manuscript and approved the final manuscript. Yan Wang helped design the study, and critically reviewed the manuscript for important intellectual content.

Disclosures. Xiaoyan Yang, Qian Fan, Yue Zhang, Xiaoqin Chen, Yanglin Jiang, Haohan Zou, Mengdi Li, Lihua Li, and Yan Wang declare no conflicts of interest.

Compliance with Ethics Guidelines. The ethics board of the Tianjin Eye Hospital, Tianjin, China, approved this school-based cohort study (No. 2021022), which adhered to the tenets of the Declaration of Helsinki of 1964 and its later amendments. Informed consent was obtained from all participants and their parents or legal guardians. Oral assent was obtained from all children before each examination.

Data Availability. The datasets generated and analyzed during the current study are not publicly available at this time as the data also forms part of an ongoing study.

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