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Objective and Subjective Behavioral Measures in Myopic and Non-Myopic Children During the COVID-19 Pandemic

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Purpose: The coronavirus disease 2019 (COVID-19) pandemic required a shift to electronic devices for education and entertainment, with children more confined to home, which may affect eye growth and myopia. Our goal was to assess behaviors during COVID-19 in myopic and non-myopic children.

Methods: Parents completed a questionnaire for their children (ages 8.3 ± 2.4 years, $n = 53$) regarding visual activity in summer 2020, during the COVID-19 pandemic, as well as during school time and the summer before COVID-19. Children also wore an Actiwatch for 10 days in summer 2020 for objective measures of light exposure, activity, and sleep. Data were analyzed with repeated-measures analysis of variance.

Results: Subjective measures showed that during COVID-19, children exhibited increased electronic device use and decreased activity and time outdoors ($P < 0.05$ for all), while time spent doing near work was not different than during a typical school or summer session before COVID-19 ($P > 0.05$). Objective measures during COVID-19 showed that myopic children exhibited lower daily light exposure ($P = 0.04$) and less activity ($P = 0.04$) than non-myopic children.

Conclusions: Children demonstrated increased electronic device use and decreased activity and time outdoors during COVID-19, with myopic children exhibiting lower light exposure and activity than non-myopes. Long-term follow-up is needed to understand if these behavioral changes ultimately contribute to myopia progression.

Translational Relevance: Children's behaviors changed during the COVID-19 pandemic, which may have implications in eye growth and myopia.

Introduction

The first case of coronavirus disease 2019 (COVID-19) in United States was identified in January 2020,[1] and by early March, the first case in Houston, Texas, was diagnosed. Soon after, officials issued a stay-at-home order to slow the spread of the virus and reduce pressure on the health care system. Secondary to quarantine and lockdown measures, children's lifestyles dramatically changed. All schools closed for in-person learning, and children shifted to electronic devices for virtual education, social interactions, and entertainment. These stay-at-home orders likely resulted in significant changes in the amount of time that children spent outdoors, engaged in near work, and used screens. Near work and time outdoors are both considered factors that can affect eye growth and myopia, or nearsightedness, in children.[2–8]

Myopia is the result of a mismatch between optical power of the eye and its length. It is the most common type of refractive error and is considered a major cause of preventable visual impairment in the world.[9,10] Currently, 22.9% of the world population (1.4 billion) is myopic, and its prevalence is expected to increase to 4.8 billion by 2050.[11] Myopia represents a significant socioeconomic burden globally[12] and, if left uncorrected, can affect school performance of children and quality of life.[13] While the exact etiology is still unknown, myopia is thought to be the result of complex interactions between genetic, environmental, and behavioral factors.[14–19] There is an abundance of literature suggesting an association between time spent outdoors and light exposure with the development and progression of myopia in children.[2–5,20] According to these studies, less outdoor time and lower light exposure are correlated with increased myopia prevalence and, in some reports, also with myopia progression.[5,20] However, evidence concerning the role of near work in myopia onset and progression is conflicting. Many authors report that increased near work is associated with higher incidence of myopia in school-age children,[6–8] while others did not observe such a relationship.[21–24] In addition, the contributions of screen time in myopia are not well understood. A recent review reported mixed findings with respect to an influence of screen time on myopia.[25]

The goal of this study was to assess subjective and objective measures of physical activity, outdoor time, near work, electronic device use, and sleep during summer 2020, while COVID-19–related quarantine measures were in place, in myopic and non-myopic children, in the Houston area. Behaviors were compared with a typical summer and school session prior to the COVID-19 pandemic using a questionnaire.

Methods

Healthy children between the ages of 5 and 12 years were recruited for this study through advertisements posted to faculty and staff of the University of Houston, word of mouth, and neighborhood Facebook groups. Written permission was obtained from all parents, and children provided assent. The study followed the tenets of the Declaration of Helsinki and was approved by the University of Houston Institutional Review Board. Data were collected between July and August 2020 and did not include any in-lab visits in order to maintain social distancing and minimize spread of the virus. During this time, schools and summer activities were shut down due to COVID-19. Consent forms were delivered electronically. Upon verbal consent, study material was delivered to participants' address and left in mailbox or front porch for parents to retrieve. Signatures were obtained when material was delivered. After finishing the study, material was collected in the same manner by study personnel.

Subjective Measures Using Questionnaires

Parents were asked to complete an activity questionnaire, the University of Houston Near Work, Environment, Activity, and Refraction (UH NEAR) survey (originally developed based on the questionnaire used in the Sydney Myopia Study and adapted here for assessment during the COVID-19 pandemic),[2,26] for their children (see the supplementary file for the complete questionnaire used here). The survey included questions regarding demographics, ocular history, and visual activity. Parents filled out the survey for their children, which included three sets of questions, corresponding to three time sessions: (1) summer 2020 while COVID-19–related quarantine measures were in place for Houston, (2) a typical school session before COVID-19 (i.e., fall 2019), and (3) a typical summer session before COVID-19 (i.e., summer 2019). The order of the questions was similar for all participants, and observations from previous studies in which this questionnaire was used suggest that the total time to complete all three sets of questions was less than 15 minutes. Since there were no in-lab visits, classification of refractive status (myopic or non-myopic) was based on a questionnaire using an indirect method technique. This method asks a series of questions about the use of eyeglasses and age of first dispensing and has been shown to have reasonable sensitivity and specificity (0.76 and 0.74, respectively) for determining whether a participant is myopic.[27] Visual activity was assessed through questions about time spent outdoors, time in physical activities, and time doing near work (printed materials, computers, TV, and handheld electronic devices asked as separate items) on weekdays and weekends.

Near work was defined as the sum of hours per day spent viewing handheld electronic devices + reading printed materials such as book + writing, drawing, painting, and crafting. Electronic device use was defined as hours per day spent viewing handheld electronic devices + computer + TV. Physical activity was defined as hours per day spent in outdoor and indoor physical activities. Time outdoors was defined as hours per day of outdoor physical and leisure activities plus driving and riding in vehicle. Mean daily hours spent on each activity was calculated using the following equation:

$$\text{Mean daily hours} = [(\text{weekday hours} \times 5) + (\text{weekend hours} \times 2)]/7 \quad (1)$$

Objective Measures Using Wearable Sensors

In addition to questionnaires, children were asked to wear an actigraph device (Actiwatch Spectrum Plus; Philips Respironics, Bend, OR, USA) continuously for 10 days and nights during summer 2020. The Actiwatch Spectrum Plus is a small noninvasive wrist-worn activity monitoring and light-sensing device that measures physical activity, sleep, and ambient illumination. The Actiwatch has been widely used in behavioral and sleep studies in children and adults.[3,28–30] The device is waterproof for up to 30 minutes and the battery lasts for up to 60 days when fully charged. The Actiwatch was set to average over 1-minute epochs. The device has a solid-state piezoelectric accelerometer with a 32-Hz sampling rate to measure physical activity in counts per minutes (CPM). From accelerometry, the software (Actiware 6.0.9) also provides sleep parameters, including wake time, sleep time, and sleep duration. Daily physical activity was calculated by averaging CPM for each participant's wake period. Ambient illumination is measured by color-sensitive photodiodes to quantify average daily light exposure (lux), daily cumulative light exposure (lux), and minutes spent outdoors (ambient illumination >1000 lux).[3,30,31] A previous study showed that at least one week of Actiwatch wear provides the most reliable estimate of outdoor light exposure for children.[32] Sleep parameters were averaged across weekday nights (Sunday to Thursday nights) and weekend nights (Friday and Saturday nights). Similarly, light exposure and physical activity parameters were averaged across weekdays (Monday to Friday) and weekend days (Saturday to Sunday).

Data Analysis

Results are presented as mean ± standard error, unless otherwise noted. Statistical analysis was performed with SPSS 26 (IBM Corp., Armonk, NY, USA). Three-way repeated-measures analyses of variance (ANOVAs) were conducted to examine the effect of session and day of week (within-subject factors) and refractive error group (between-subject factor), as well as their interactions on subjective measures of sleep, time outdoors, physical activity, near work, and electronic device use. Session included three levels (COVID-19, typical summer, typical school). Day of week included two levels (weekday and weekend). Statistically significant interactions were followed by Bonferroni-adjusted pairwise comparisons. To compare objective measures of sleep, activity, and light exposure between refractive error groups, two-way repeated-measures ANOVAs with refractive error group as between-subject factor and day of the week as within-subject factor were conducted. While objective measures of time outdoors and sleep duration were available for the COVID-19 session, only subjective measures of time outdoors and sleep duration were available for a typical summer and a typical school session. Therefore, we have included time outdoors and sleep duration in both the subjective and objective analyses. To assess potential differences between objective and subjective measures of sleep duration and time outdoors, questionnaire data and Actiwatch data were compared using paired *t*-tests.

Results

Participants included 53 children, ages 8.3 ± 2.4 years (mean ± standard deviation; range, 5–12), including 14 myopes (ages 8.9 ± 2.3 years; 95% confidence interval [CI], 7.9–10.4) and 39 non-myopes (ages 8.1 ± 2.4 years; 95% CI, 7.3–8.8). Parent-reported race of the children was predominantly white ($n = 39$), followed by African American ($n = 7$), Asian ($n = 5$), mixed ($n = 1$), and unknown ($n = 1$). Ethnicity was self-reported as Hispanic for 10 children and non-Hispanic for 43 children. Race and ethnicity classification were based on recommendations from the US Census Bureau.[33]

Subjective Measures

Questionnaire-derived results for each of the three sessions, COVID-19, a typical summer, and a typical school session, are shown in the Table. One participant was excluded from analysis of subjective measures because the values reported by parents were out of range and identified as extreme outliers; the parent estimated that the child had only 1 hour of sleep per night, 26 hours of near work per day, and 23 hours of outdoor time per day.

For subjective measures of time outdoors, a significant interaction between session and day of the week was observed ($P = 0.006$). Pairwise comparison showed that on weekdays, children spent less time outdoors during COVID-19 than during a typical summer ($P = 0.001$) but similar to a typical school session ($P = 1.0$). Based on parent report, average time outdoors on weekdays during the 2020 summer of COVID-19 was 2 hours less per day than during a typical summer before COVID-19 (Fig. 1A). On weekends, however, there was no significant difference in time spent outdoors between COVID-19 and other two sessions, and there were no significant differences between refractive error groups ($P = 0.20$).

Subjective measures of physical activity did not vary by refractive error group ($P = 0.70$), but the interaction between session and day of the week was significant ($P = 0.046$). Parents reported that on weekdays during COVID-19, children spent less time engaged in physical activity (3.2 ± 0.4 hours/d) than during a typical summer (4.3 ± 0.4 hours/d, $P = 0.002$) but similar to a typical school session (3.2 ± 0.2 hours/d, $P = 1.0$) (Fig. 1B).

Table. Children's Questionnaire-Derived Metrics

	COVID-19 (Summer 2020)		Typical Summer		Typical School Session	
Characteristic	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Time outdoors (hours per day)						
Myopes	3.7 ± 4.2	5.1 ± 4.3	6.6 ± 3.5	7.8 ± 4.4	4.1 ± 2.0	6.2 ± 3.0
Non-myopes	4.6 ± 3.6	5.4 ± 3.5	5.8 ± 2.9	5.6 ± 2.9	4.3 ± 2.0	5.6 ± 2.8
P value			.007*			
Physical activity (hours per day)						
Myopes	2.9 ± 2.0	3.2 ± 1.9	4.2 ± 2.6	4.2 ± 2.4	3.0 ± 1.3	3.2 ± 1.1
Non-myopes	3.5 ± 2.3	3.7 ± 1.9	4.4 ± 2.5	3.7 ± 2.5	3.4 ± 1.6	3.4 ± 2.0
P value			.002*			
Electronic device use (hours per day)						
Myopes	7.8 ± 4.2	8.7 ± 5.0	5.6 ± 3.3	6.9 ± 4.0	3.6 ± 2.1	6.0 ± 4.0
Non-myopes	6.8 ± 3.7	7.2 ± 3.8	4.2 ± 2.8	5.2 ± 2.9	3.2 ± 2.1	4.8 ± 2.7
P value			<.001*			
Near work (hours per day)						
Myopes	5.1 ± 1.9	5.0 ± 2.1	4.9 ± 1.8	5.2 ± 2.5	4.7 ± 1.8	5.3 ± 2.2
Non-myopes	4.6 ± 2.4	4.4 ± 2.1	3.7 ± 1.8	3.7 ± 1.8	4.8 ± 2.5	4.1 ± 2.4
P value			.3			
Sleep (hours per day)						
Myopes	8.9 ± 1.1	9.0 ± 1.1	8.7 ± 1.4	9.2 ± 1.2	8.2 ± 0.7	9.1 ± 1.1
Non-myopes	9.4 ± 1.2	9.6 ± 1.1	9.4 ± 1.1	9.4 ± 1.1	9.3 ± 1.1	9.3 ± 1.2
P value			.13			

Mean ± standard deviation hours per day spent outdoors, in physical activity, using electronic devices, engaged in near work, and sleep duration for myopic ($n = 13$) and non-myopic ($n = 39$) children during COVID-19, a typical summer, and a typical school session on weekdays and weekends. *P* value is shown for the main effect of session.

*Significant at $P < 0.05$.

Daily electronic device use increased on weekdays and weekends during COVID-19 (7.3 ± 0.6 and 7.9 ± 0.7 hours) compared to a typical summer (4.9 ± 0.5 and 6.1 ± 0.5 hours, $P < 0.001$ for both weekdays and weekends) and to a typical school session (3.4 ± 0.3 and 5.4 ± 0.5 hours, $P < 0.001$ for both weekdays and weekend) (Fig. 1C). For all sessions, electronic device use was longer on weekends compared to weekdays ($P = 0.047$, $P = 0.001$, and $P < 0.001$ for COVID-19, typical summer, and typical school sessions, respectively). Time spent doing near work was not significantly different between sessions, days of the week, or refractive error groups ($P > 0.05$ for all) (Fig. 1D).

For subjective measures of sleep duration, there was a statistically significant three-way interaction between session, refractive error group, and day of the week on sleep duration ($P = 0.04$). Follow-up analysis showed that during a typical school session, myopic children slept 51 minutes longer on weekends compared with weekdays ($P = 0.004$), and on weekdays, myopes slept 64 minutes less compared with non-myopes ($P = 0.002$). However, for a typical summer and for the COVID-19 summer, there were no significant interactions between refractive error group and day of the week ($P > 0.05$ for all).

Objective Measures during COVID-19

On average, children wore the Actiwatch for 7 ± 1 weekdays and 2.4 ± 0.7 weekend days. Children's Actiwatch-derived objective measures are shown by refractive error group and day in Figure 2. During COVID-19, myopic children had significantly lower daily light exposure (183.6 ± 39.3 lux) than non-myopic children (279.5 ± 23.5 lux, $P = 0.04$), with no differences between weekdays and weekends. However, while myopic children tended to spend less time outdoors (0.7 ± 0.2 hours per day) than non-myopic children (1.0 ± 0.1 hours per day), the difference did not reach significance ($P = 0.09$). Myopic children demonstrated less physical activity during COVID-19 than non-myopic children ($P = 0.04$). Mean difference between

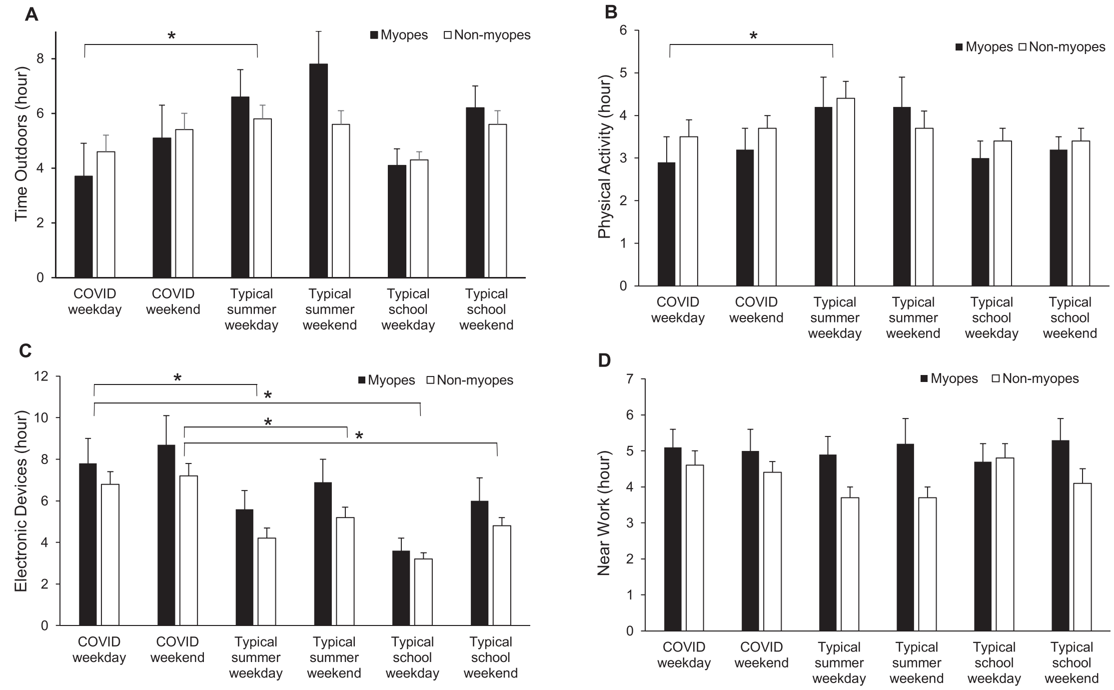

Figure 1. Questionnaire-derived mean daily hours spent in (A) outdoor time, (B) physical activity, (C) electronic device use, and (D) near work for myopic (*filled bars*) and non-myopic (*open bars*) children on weekdays and weekends for the COVID-19 session, a typical summer session, and a typical school session. *Error bars* represent standard error. *Asterisks* represent statistically significant differences ($P < 0.05$) determined by three-way repeated-measures ANOVAs.

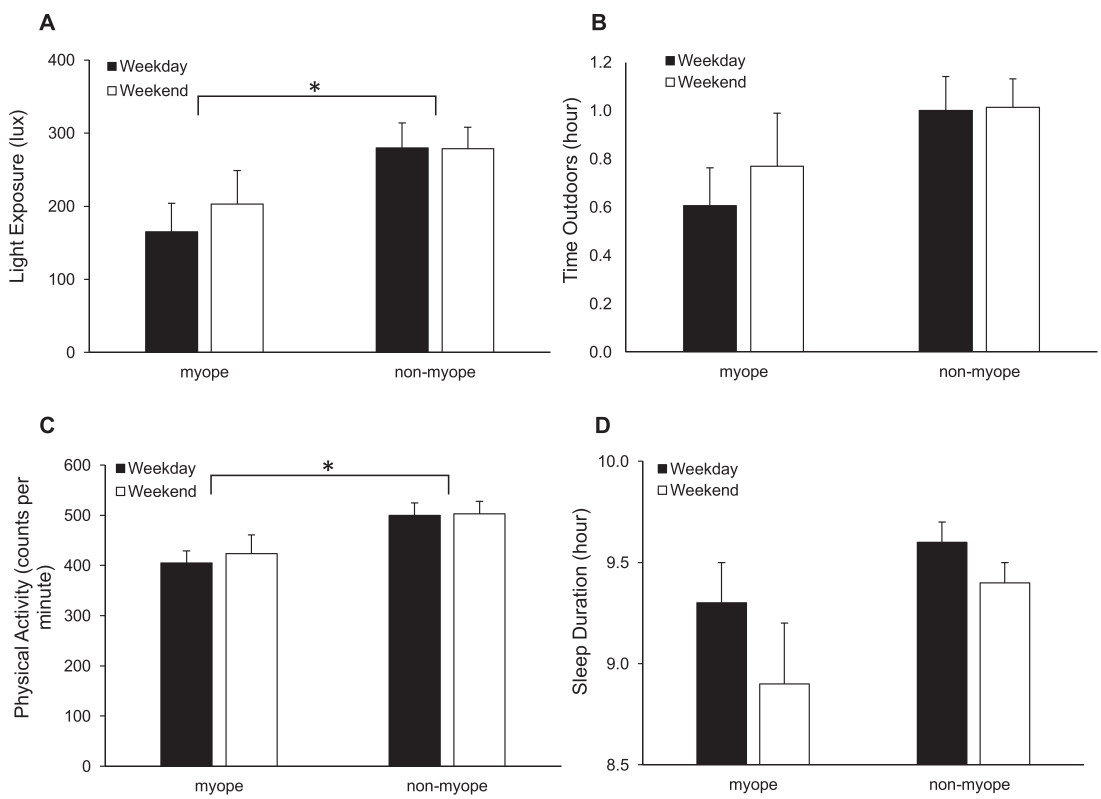

Figure 2. Children's Actiwatch-measured (A) daily light exposure (lux), (B) time outdoors (hours), (C) physical activity (counts per minute), and (D) sleep duration (hours) for each refractive error group on weekdays and weekends during COVID-19. *Error bars* represent standard error. *Significance at $P < 0.05$.

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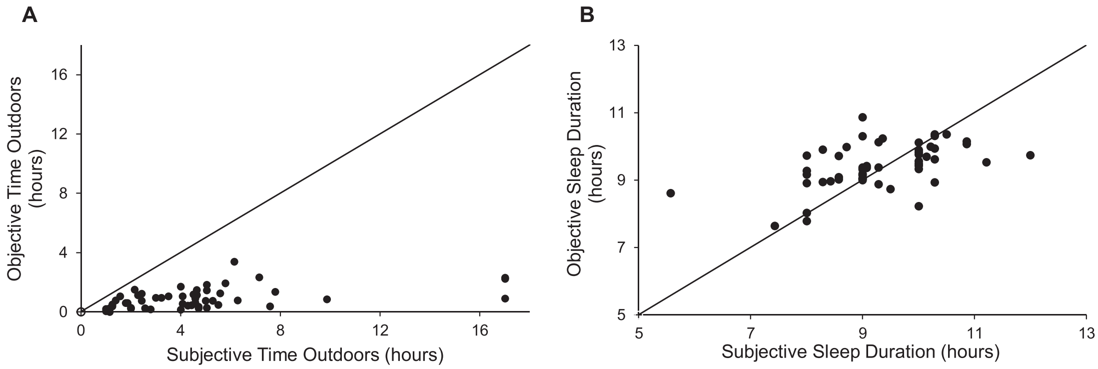

Figure 3. Subjective versus objective measures of mean daily (A) time outdoors (hours) and (B) sleep duration (hours) for all children during summer 2020. *Solid line* represents the 1:1 relationship.

two groups was 87 CPM. Sleep duration was not significantly different between refractive error groups ($P = 0.06$), with a mean daily duration of 9.4 ± 0.1 hours.

Comparing Objective and Subjective Measures during COVID-19

During the COVID-19 session, both subjective questionnaire-derived data and objective Actiwatch-measured data were available for time spent outdoors and sleep duration in children (Fig. 3). Time outdoors was significantly different between two methods ($P < 0.0001$), with parents reporting 4.6 ± 0.5 hours outdoors per day during COVID-19 compared with Actiwatch-measured time outdoors (exposed to >1000 lux) per day of 0.9 ± 0.1 hours. Three data points were identified as outliers (Fig. 3A). However, removing them did not change the results of the paired *t*-test used to compare objective and subjective measurements. There were no significant differences between objective and subjective measures of sleep duration during quarantine ($P = 0.32$).

Discussion

Behavioral differences between myopic and non-myopic children have been well studied; however, previous findings cannot be extrapolated to how children may behave during an unprecedented pandemic era. The goal of this study was to assess sleep, time outdoors, physical activity, near work, and electronic device use during the COVID-19 pandemic (summer 2020) in myopic and non-myopic children and to compare these behaviors with a typical time prior to the COVID-19 pandemic. Children's behaviors changed during the COVID-19 pandemic and varied between myopes and non-myopes. Based on parent report, children's electronic device use increased, and physical activity and time outdoors decreased during COVID-19. Objective measures showed that during COVID-19, myopic children exhibited lower daily light exposure and physical activity than non-myopes.

Our subjective results confirm a significant increase in electronic device use during COVID-19 compared to pre–COVID-19 on both weekdays and weekends for children. As a result of critical measures to slow the spread of the virus during summer 2020, children's organized camps and summer activities were canceled and children were confined to home. Our findings show that children spent more time playing video games and watching shows on handheld electronic devices such as tablets and smartphones, as well as computer and TV. In addition to summer activities being canceled, the prolonged spread of COVID-19 shifted many schools to virtual learning and online classes going into fall 2020 and spring 2021 semesters. Therefore, increases in electronic device use have likely persisted. Given that the study period was summer 2020 and there were no official school classes or assignments, our study might not have fully captured the increased use of electronic devices during the COVID-19 pandemic that resulted from a shift to virtual education. Speculation exists whether increased electronic device use and near work during the COVID-19 pandemic will affect myopia development and progression.[34,35] Although many studies have reported that use of electronic devices and longer screen time are associated with a higher rate of myopia in children,[36,37] a recent meta-analysis argues that the results are mixed and not convincing.[25] Such discrepancies highlight the importance of objective measures of working distance and improved methods to quantify screen time. Working distance (<30 cm) was reported to be linked to higher risk of developing myopia in a Sydney myopia study.[17] Objective measures of working distance have shown that myopic children spent more time on activities at distances <20 cm compared to non-myopic children.[38] Our results show that during COVID-19, use of handheld electronic devices was significantly more than sessions prior to the pandemic. As the distance to hold such devices is often <30 cm,[39] such increases may eventually affect myopia development in children.

Despite increased use of handheld electronic devices during COVID-19, time spent on near work was not significantly different for children during COVID-19 in the summer. In our study, near work was defined as sum of hours per day spent using handheld electronic devices, reading printed materials, and writing and drawing. Increased use of handheld electronic devices was accompanied with shorter duration of reading printed materials and writing. The average time spent reading and writing during the summer COVID-19 pandemic, as well as for a typical summer, was 2.4 hours per day but was 3 hours (outside of school) during a typical school session.

Based on the questionnaire, children used electronic devices more during the COVID-19 pandemic. Electronic devices such as smartphones, tablets, and computer monitors emit short-wavelength light in the blue range of the spectrum. Exposure to artificial blue light emitted by such devices, especially in the evening, may suppress melatonin, the sleep-promoting hormone; shift the circadian clock[40,41]; alter sleep/wake pattern; and reduce sleep quality in children.[42,43] Sleep duration and quality are thought to be major influencers on academic performance in children and adolescents.[44,45] Despite the increase in electronic device use, average sleep duration for children during the COVID-19 pandemic was not significantly different from typical school and summer sessions. Considering that the period of data collection was during the early phase of the pandemic, it is possible that increased screen time did not affect sleep duration immediately. Additionally, sleep duration and quality might be affected by many factors during the pandemic,[46–48] which makes it challenging to assess the sole effect of screen time. Nonetheless, objective longitudinal studies are needed to elucidate the effects of increased screen time on sleep pattern, duration, and quality.

During the COVID-19 pandemic, myopic children exhibited significantly lower daily light exposure compared to non-myopic children, as measured objectively using the Actiwatch. Trends suggest that time spent outdoors was also lower in myopic children; however, these differences did not reach statistical significance. The finding of lower daily light exposure in myopes is consistent with previous studies, before COVID-19, which measured light exposure objectively.[3,49]

Based on previous objective measurements from our laboratory during summer 2017,[30] in 60 children aged 5 to 10 years, mean daily physical activity, sleep duration, and outdoor time were 564 ± 18 CPM, 9.3 ± 0.1 hours, and 110 ± 6 minutes, respectively. Our objective measurements during the COVID-19 pandemic (using similar Actiwatch) showed almost 100 CPM less physical activity (479 ± 19 CPM) and half of the time outdoors (55 ± 6 minutes) but almost similar sleep duration (9.4 ± 0.1 hours). Mean daily light exposure between two studies was remarkably different: 255 lux in the current study compared to almost 2000 lux in the previous study. Mean daily light exposure measured during the COVID-19 pandemic was even less than spring (1500 lux) and summer (1000 lux) values reported in the previous study. Although age range of children in our current study (5 to 12 years old) was slightly wider compared to the previous study (5 to 10 years old), mean age was comparable (8.3 and 7.6 years for the current and previous studies, respectively). Additionally, percentage of myopic children in both studies was similar (26% in the current study compared to 17% in the previous study).

According to the questionnaire, time spent outdoors for children in the summer during the COVID-19 pandemic was on average 2 hours less per day compared to their typical summer prior to COVID-19. Although it was significantly less than a typical summer session, estimated outdoor time was 4.6 ± 0.5 hours per day during the COVID-19 summer, which seems high considering the stay-at-home order in place and does not seem to represent changes in outdoor time during the pandemic. Objective data from the Actiwatch, however, show that outdoor time was on average less than an hour per day. Outdoor time is known to have a protective effect against myopia, and many studies indicated that more time outdoors lowers the odds ratio of myopia.[2,50,51] An additional hour of time outdoors for children reduces odds of myopia by 2% in a meta-analysis study after adjusting for confounders.[52] As discussed above earlier, in a study previously conducted in our laboratory,[30] time outdoors, measured objectively using the Actiwatch, during summer 2017 for 60 children aged 5 to 10 years was on average 110 minutes, which is almost 1 hour more compared to children's outdoor time in the current study during the summer COVID-19 pandemic. These findings suggest that decreased outdoor time during the COVID-19 pandemic may lead to increases in myopia in the future.

The average level of physical activity (measured objectively) was lower in myopic compared to non-myopic children. Many questionnaire-based studies reported a similar trend in children.[6,53,54] Some groups quantified physical activity objectively using an accelerometer[3,30,55,56]; however, even objective reports in various studies are conflicting. The association between physical activity and myopia is confounded by time outdoors. In our cohort, we observed a significant correlation between time spent outdoor and physical activity ($r = .35$, $P = 0.01$). However, only the latter was significantly different between refractive error groups. Whether physical activity has an independent effect on myopia development and progression or its effect is related to time outdoors requires further investigation.

It is well established that environmental factors affect myopia development and eye growth. The COVID-19 pandemic has provided a unique experimental opportunity to observe how myopes and non-myopes respond to an environmental situation that affects both refractive error groups. Some differences observed between refractive error groups are what we would expect during the non–COVID-19 time. We expected less light exposure in the myopic group based on previous findings, but we also found less physical activity for myopes during the COVID-19 session, whereas Read et al.[3] did not observe significant differences in physical activity between myopic and emmetropic children. Likewise, in previous longitudinal studies, researchers found no association between physical activity and myopia in children.[30,57]

Myopic children slept longer on weekends compared with weekdays during a typical school session, as determined by parent report. Variation in sleep duration between days of the week is of importance as studies suggest its negative physiologic effect.[58,59] Our finding is consistent with objective findings of Ostrin et al.[28] However, the number of myopic children in our study was small; future studies should include a larger sample size to better understand the link between myopia and sleep duration.

The long-term impact of the COVID-19 pandemic and corresponding preventive strategies on myopia development and progression may not be known for some time. A recent cross-sectional vision screening study in China reported that children aged 6 to 8 years showed a significant myopic shift in 2020 compared to the same age group from 2015 to 2019.[60] Children in that study were screened in June 2020, after 6 months of home confinement. Longer follow-up is needed to understand how the COVID-19 pandemic contributes to increased myopia onset and progression in different parts of the world, especially in countries where the incidence of myopia was already rising.

Limitations of our study included a small sample size with a limited number of myopic children. The children in this study were primarily white, with smaller numbers of African Americans and Asians. This ethnic distribution approximately matches that of Houston, Texas,[61] but does lack diversity. As classification of the refractive error group was done indirectly to maintain social distancing during the height of quarantine, there is a possibility of misclassification of refractive status of participants, and we cannot comment on the distribution of participants' refractive error. Furthermore, children wore the Actiwatch only for 10 days, which may not necessarily represent the spectrum of children's behavior during the entire 3 months of summer 2020. Moreover, questionnaire-derived assessment of behavior is subject to recall bias, and estimates of total activities were greater than 24 hours in some cases. Hence, future studies should focus on using objective measures to quantify visual activities such as near work. Additionally, in our study, parents completed the questionnaire for their children, and as many parents were also working from home, they might not have fully observed children's engagement in various activities. Another limitation of the study is that we do not know which parent completed the survey or have any information on how much time the parents actually spent with their child.

In conclusion, we objectively quantified light exposure, physical activity, and sleep in a cohort of children during the COVID-19 pandemic. We also used a questionnaire to compare behaviors to those before the COVID-19 pandemic for children. Our results indicate that children's use of electronic devices increased while their physical activity and time outdoors decreased during the pandemic compared to before the pandemic. Objective measures acquired during the pandemic showed that myopic children exhibited significantly lower daily light exposure and physical activity compared to non-myopic children. As the COVID-19 pandemic and quarantine-related measures continue in many countries, it is important to document behavioral changes in larger cohorts to understand contributions to myopia onset and progression in children.

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References

1. Centers for Disease Control and Prevention. First travel-related case of 2019 novel coronavirus detected in United States. https://www.cdc.gov/media/releases/2020/p0121-novel-coronavirus-travel-case.html. Accessed December 20, 2020.
2. Rose KA, Morgan IG, Ip J, et al. Outdoor activity reduces the prevalence of myopia in children. *Ophthalmology*. 2008;115:1279–1285.
3. Read SA, Collins MJ, Vincent SJ. Light exposure and physical activity in myopic and emmetropic children. *Optom Vis Sci*. 2014;91:330–341.
4. Guo Y, Liu LJ, Xu L, et al. Myopic shift and outdoor activity among primary school children: one-year follow-up study in Beijing. *PLoS One*. 2013;8:e75260.
5. Guo Y, Liu LJ, Tang P, et al. Outdoor activity and myopia progression in 4-year follow-up of Chinese primary school children: the Beijing Children Eye Study. *PLoS One*. 2017;12:1–14.
6. Mutti DO, Mitchell GL, Moeschberger ML, et al. Parental myopia, near work, school achievement, and children's refractive error. *Invest Ophthalmol Vis Sci*. 2002;43:3633–3640.
7. French AN, Morgan IG, Mitchell P, et al. Risk factors for incident myopia in Australian schoolchildren: the Sydney Adolescent Vascular and Eye Study. *Ophthalmology*. 2013;120:2100–2108.
8. Lin Z, Vasudevan B, Mao GY, et al. The influence of near work on myopic refractive change in urban students in Beijing: a three-year follow-up report. *Graefe's Arch Clin Exp Ophthalmol*. 2016;254:2247–2255.
9. Congdon NG, Friedman DS, Lietman T. Important causes of visual impairment in the world today. *JAMA*. 2003;290:2057–2060.
10. Morgan IG, Ohno-Matsui K, Saw S. Myopia. *Lancet*. 2012;379:1739–1748.
11. Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology*. 2016;123:1036–1042.
12. Foster PJ, Jiang Y. Epidemiology of myopia. *Eye*. 2014;28:202–208.
13. Congdon N, Burnett A, Frick K. The impact of uncorrected myopia on individuals and society. *Community Eye Health*. 2019;32:7–8.
14. Hammond CJ, Snieder H, Gilbert CE, et al. Genes and environment in refractive error: the Twin Eye Study. *Invest Ophthalmol Vis Sci*. 2001;42:1232–1236.
15. Lyhne N, Sjølie AK, Kyvik KO, et al. The importance of genes and environment for ocular refraction and its determiners: a population based study among 20–45 year old twins. *Br J Ophthalmol*. 2001;85:1470–1476.
16. Ip JM, Rose KA, Morgan IG, et al. Myopia and the urban environment: findings in a sample of 12-year-old Australian school children. *Invest Ophthalmol Vis Sci*. 2008;49:3858–3863.
17. Ip JM, Saw S-M, Rose KA, et al. Role of near work in myopia: findings in a sample of Australian school children. *Invest Ophthalmol Vis Sci*. 2008;49:2903–2910.
18. Liang YB, Lin Z, Vasudevan B, et al. Generational difference of refractive error in the baseline study of the Beijing Myopia Progression Study. *Br J Ophthalmol*. 2013;97:765.
19. Verhoeven VJM, Hysi PG, Wojciechowski R, et al. Genome-wide meta-analyses of multiancestry cohorts identify multiple new susceptibility loci for refractive error and myopia. *Nat Genet*. 2013;45:314–318.
20. Read SA, Collins MJ, Vincent SJ. Light exposure and eye growth in childhood. *Invest Ophthalmol Vis Sci*. 2015;56:6779–6787.
21. Saw S-M, Shankar A, Tan S-B, et al. A cohort study of incident myopia in Singaporean children. *Invest Ophthalmol Vis Sci*. 2006;47:1839–1844.
22. Jones-Jordan LA, Sinnott LT, Cotter SA, et al. Time outdoors, visual activity, and myopia progression in juvenile-onset myopes. *Invest Ophthalmol Vis Sci*. 2012;53:7169–1775.
23. Wu PC, Tsai CL, Wu HL, et al. Outdoor activity during class recess reduces myopia onset and progression in school children. *Ophthalmology*. 2013;120:1080–1085.
24. Lin Z, Vasudevan B, Jhanji V, et al. Near work, outdoor activity, and their association with refractive error. *Optom Vis Sci*. 2014;91:376–382.
25. Lanca C, Saw SM. The association between digital screen time and myopia: a systematic review. *Ophthalmic Physiol Opt*. 2020;40:216–129.
26. Williams R, Bakshi S, Ostrin EJ, et al. Continuous objective assessment of near work. *Sci Rep*. 2019;9:1–10.
27. Walline JJ, Zadnik K, Mutti DO. Validity of surveys reporting myopia, astigmatism, and presbyopia. *Optom Vis Sci*. 1996;73:376–381.
28. Ostrin LA, Read SA, Vincent SJ, et al. Sleep in myopic and non-myopic children. *Transl Vis Sci Technol*. 2020;9:1–13.

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29. Bélanger M-È, Bernier A, Paquet J, et al. Validating actigraphy as a measure of sleep for preschool children. *J Clin Sleep Med*. 2013;9:701–706.
30. Ostrin LA, Sajjadi A, Benoit JS. Objectively measured light exposure during school and summer in children. *Optom Vis Sci*. 2018;95:332–342.
31. Dharano R, Lee C-F, Theng ZX, et al. Comparison of measurements of time outdoors and light levels as risk factors for myopia in young Singapore children. *Eye*. 2012;26:911–918.
32. Ulaganathan S, Read SA, Collins MJ, et al. Measurement duration and frequency impact objective light exposure measures. *Optom Vis Sci*. 2016;94:588–597.
33. United States Census Bureau. About race. https://www.census.gov/topics/population/race/about.html. Accessed March 15, 2021.
34. Wai WC, Tsai A, Jonas JB, et al. Digital screen time during COVID-19 pandemic: risk for a further myopia boom? *Am J Ophthalmol*. 2020;223:333–337.
35. Sumitha M, Sanjay S, Kemmanu V, et al. Will COVID-19 pandemic-associated lockdown increase myopia in Indian children? *Indian J Ophthalmol*. 2020;68:1496.
36. Saw SM, Chua WH, Hong CY, et al. Nearwork in early-onset myopia. *Invest Ophthalmol Vis Sci*. 2002;43:332–339.
37. Yang GY, Huang LH, Schmid KL, et al. Associations between screen exposure in early life and myopia amongst Chinese preschoolers. *Int J Environ Res Public Health*. 2020;17:1–16.
38. Wen L, Cao Y, Cheng Q, et al. Objectively measured near work, outdoor exposure and myopia in children. *Br J Ophthalmol*. 2020;104:1542–1547.
39. Bhandari KR, Ostrin LA. Investigation of working distances in myopic and non-myopic children. *Optom Vis Sci.* 2020;97:E-abstract 200050.
40. Cajochen C, Frey S, Anders D, et al. Evening exposure to a light-emitting diodes (LED)-backlit computer screen affects circadian physiology and cognitive performance. *J Appl Physiol*. 2011;110:1432–1438.
41. Lockley SW, Brainard GC, Czeisler CA. High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. *J Clin Endocrinol Metab*. 2003;88:4502–4505.
42. Higuchi S, Nagafuchi Y, Lee S, et al. Influence of light at night on melatonin suppression in children. *J Clin Endocrinol Metab*. 2014;99:3298–3303.
43. Magee CA, Lee JK, Vella SA. Bidirectional relationships between sleep duration and screen time in early childhood. *JAMA Pediatr*. 2014;168:465–470.
44. Dewald JF, Meijer AM, Oort FJ, et al. The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: A meta-analytic review. *Sleep Med Rev*. 2010;14:179–189.
45. Hysing M, Harvey AG, Linton SJ, et al. Sleep and academic performance in later adolescence: results from a large population-based study. *J Sleep Res*. 2016;25:318–324.
46. Xiao H, Zhang Y, Kong D, et al. Social capital and sleep quality in individuals who self-isolated for 14 days during the coronavirus disease 2019 (COVID-19) outbreak in January 2020 in China. *Med Sci Monit*. 2020;26:e923921.
47. Guessoum SB, Lachal J, Radjack R, et al. Adolescent psychiatric disorders during the COVID-19 pandemic and lockdown. *Psychiatry Res*. 2020;291:113264.
48. Li Y, Qin Q, Sun Q, et al. Insomnia and psychological reactions during the COVID-19 outbreak in China. *J Clin Sleep Med*. 2020;16:1417–1418.
49. Wu PC, Chen CT, Lin KK, et al. Myopia prevention and outdoor light intensity in a school-based cluster randomized trial. *Ophthalmology*. 2018;125:1239–1250.
50. Jones LA, Sinnott LT, Mutti DO, et al. Parental history of myopia, sports and outdoor activities, and future myopia. *Invest Ophthalmol Vis Sci*. 2007;48:3524–3532.
51. Yang M, Luensmann D, Fonn D, et al. Myopia prevalence in Canadian school children: a pilot study. *Eye*. 2018;32:1042–1047.
52. Sherwin JC, Reacher MH, Keogh RH, et al. The association between time spent outdoors and myopia in children and adolescents: a systematic review and meta-analysis. *Ophthalmology*. 2012;119:2141–2151.
53. Khader YS, Batayha WQ, Abdul-Aziz SMI, et al. Prevalence and risk indicators of myopia among schoolchildren in Amman, Jordan. *East Mediterr Heal J*. 2006;12:434–439.
54. O'Donoghue L, Kapetanankis V V, McClelland JF, et al. Risk factors for childhood myopia: findings from the NICER Study. *Invest Ophthalmol Vis Sci*. 2015;56:1524–1530.
55. Guggenheim JA, Northstone K, McMahon G, et al. Time outdoors and physical activity as predictors of incident myopia in childhood: a prospective cohort study. *Invest Ophthalmol Vis Sci*. 2012;53:2856–2865.
56. Deere K, Williams C, Leary S, et al. Myopia and later physical activity in adolescence: a prospective study. *Br J Sports Med*. 2009;43:542–544.

57. Lundberg K, Suhr Thykjær A, Søgaard Hansen R, et al. Physical activity and myopia in Danish children—the CHAMPS Eye Study. *Acta Ophthalmol*. 2018;96:134–141.
58. Spruyt K, Molfese DL, Gozal D. Sleep duration, sleep regularity, body weight, and metabolic homeostasis in school-aged children. *Pediatr*. 2011;127:e345–e252.
59. Simpson NS, Diolombi M, Scott-Sutherland J, et al. Repeating patterns of sleep restriction and recovery: do we get used to it? *Brain Behav Immun*. 2016;58:142–151.
60. Wang J, Li Y, Musch DC, et al. Progression of myopia in school-aged children after COVID-19 home confinement. *JAMA Ophthalmol*. 2021;139:293–300.
61. United States Census Bureau. QuickFacts. https://www.census.gov/quickfacts/fact/table/houstoncitytexas/PST045219#qf-headnote-b. Accessed March 15, 2021.