Objective Measures of Near Viewing and Light Exposure in Schoolchildren during COVID-19

Khob R. Bhandari, BOptom, PhD,[1] Divya Shukla,[1] Hanieh Mirhajianmoghadam, MOptom, PhD,[1] and Lisa A. Ostrin, OD, PhD, FAAO[1]*

SIGNIFICANCE: Wearable sensors provide the opportunity for continuous objective measurement of the visual environment with high resolution. Our findings show that absolute and temporal properties of near viewing and time outdoors vary between myopic and nonmyopic schoolchildren, which are important considerations when studying refractive error pathogenesis.

PURPOSE: Numerous behavioral factors, including near work, time outdoors, electronic device use, and sleep, have been linked to myopia. The purpose of this study was to assess behaviors using subjective and objective methods in myopic and nonmyopic schoolchildren in the United States.

METHODS: Forty children (aged 14.6 ± 0.4 years) simultaneously wore two sensors for 1 week, a Clouclip for objective measurement of near viewing and light exposure and an Actiwatch for objective measurement of activity and sleep. Parents completed an activity questionnaire for their child. Near-viewing distance, daily duration, short-duration (>1 minute) and long-duration (>30 minutes) near-viewing episodes, light exposure, time outdoors, electronic device use, and sleep duration were analyzed by refractive error group and day of the week.

RESULTS: Objectively measured daily near-viewing duration was 6.9 ± 0.3 hours. Myopes spent more time in near + intermediate viewing than nonmyopes (P = .008) and had higher diopter hours (P = .03). Short- and long-duration near-viewing episodes were similar between groups (P < .05 for both). Daily light exposure and time outdoors were significantly lower for myopes (P < .05 for both). Electronic device use (12.0 ± 0.7 hours per day) and sleep duration (8.2 ± 0.2 hours per night) were similar between groups (P > .05 for both).

CONCLUSIONS: Objective and subjective measures confirm that myopic and nonmyopic schoolchildren exhibit different behaviors. Combining wearable sensors with questionnaires provides a comprehensive description of children's visual environment to better understand factors that contribute to myopia.

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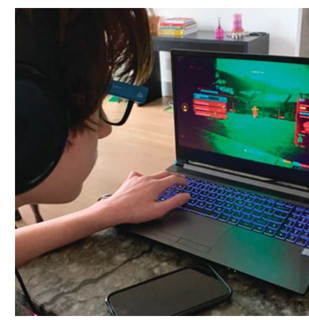

Author Affiliations:
[1]University of Houston College of Optometry, Houston, Texas
*lostrin@central.uh.edu

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The prevalence of myopia, or nearsightedness, is increasing globally.[1] Myopia is associated with increased risk of potentially sight-threatening ocular morbidities, such as cataract, glaucoma, retinal detachment, and myopic maculopathy,[2] and represents a significant socioeconomic burden.[3,4] Myopia is known to be due to a complex interaction of genetic, environmental, and behavioral factors.[5] Recent studies suggest that circadian rhythm and sleep patterns are also associated with myopia.[6] Identification of modifiable risk factors for myopia could decrease the burden and prevalence of ocular complications. However, research regarding myopiagenic risk factors in children is conflicting, likely because of the subjective methods traditionally used to quantify behaviors.

Controversy exists concerning the influence of near work on myopia. Numerous studies have linked near work with the myopia in children.[7–11] On the other hand, other studies report only a limited or no role of near work in myopia pathogenesis.[7,9,12] Accumulating evidence shows that increased time outdoors is protective against the onset of myopia in schoolchildren.[10,13–16] Although there are some inconsistencies in the literature,[17] protective effects of outdoor time against myopia onset and progression have been reported by systematic reviews and meta-analyses.[18,19] Traditionally, parent questionnaires are used to quantify these behaviors; parents are asked to estimate children's activities while they are out of school. However, questionnaires are subject to recall and parental biases,[20,21] have limited reliability and accuracy,[22] and cannot be used to estimate children's activities when they are not with their parents, such as school time. In addition, questionnaires have limited accuracy and resolution to capture temporal properties of behaviors, such as number, duration, and intensity of episodes of near viewing and light exposure. Studies show that data from questionnaires differ significantly from the objective measures.[23–25]

With advancing technology, wearable sensors, such as dosimeters (instruments that measure radiation exposure), actigraph instruments, and rangefinders, are more commonly being used for continuous, objective quantification of human behaviors, including light exposure, near viewing, and sleep/wake patterns.[24,26–28] The Actiwatch (Philips Respironics, Murrysville, PA) is a wrist-worn light sensor and accelerometer that has been used in myopia-related studies to characterize children's daily light exposure, time spent outdoors, physical activity, and sleep.[29,30] Rangefinders, such as the Clouclip (Glasson Technology Co. Ltd., Hangzhou, China),[31] RangeLife (Ostrin and Ostrin),[26] and Vivior (VIVIOR AG, Zurich, Switzerland; Mrochen M, et al. IOVS 2020;61:ARVO E-Abstract 82) have been implemented to continuously track near viewing. However, although currently available rangefinders report viewing distance, they cannot distinguish the type of object being viewed; for example, the rangefinder cannot differentiate between a printed or electronic target. With the ubiquitous use of handheld electronic devices and shifting educational systems that require screen time, speculation exists whether electronic devices, such as computers, tablets, and cell phones, could be myopiagenic.[32–34] In this sense, questionnaires are still valuable to assess aspects of behavior that cannot be captured objectively.

The goal of this study was to investigate behaviors in myopic and nonmyopic schoolchildren using subjective and objective methods to comprehensively describe the habitual visual environment during a 1-week period. Visual activity was compared across days of the week and between refractive error groups. Because of the ongoing COVID-19 pandemic and restrictive measures imposed, virtual education system required children to spend a greater proportion of time using electronic devices. This study provides the behavioral profile using objective and subjective quantification of behavioral components and describes differences between nonmyopic and myopic children during similar restrictive academic and social environments.

METHODS

Healthy children in Houston, TX, aged 10 to 18 years were recruited for this study. Ethical approval was obtained from the Committee for Protection of Human Subjects at the University of Houston, and procedures adhered to the tenets of the Declaration of Helsinki. All participants provided a written assent (<18 years old) or consent (18 years old), and parents of minors provided written permission. Data were collected between December 2020 and May 2021. This period was during the midst of the COVID-19 pandemic. No laboratory visits took place to minimize personal contact, adhering to the university's COVID-19 protocols. Some participants met at the university to dispense study material, and for others, study material was dropped off at a location convenient for them. All measurement periods took place when school was in session rather than school breaks. Most children were taking part in virtual education because of COVID-19–related school closures.

To minimize COVID-19 transmission, schools in Houston were closed for in-person learning, and virtual learning was enforced from March 2020. Beginning August 2020 and through the duration of the current study, children had the option to attend school in-person or continue from home. However, even for in-person school, classes were often still held on the computer while at school. For all children, school took place Monday through Friday. Elementary school (aged 5 to 11 years) was typically 7:30 AM to 3:00 PM, and middle school and high school (aged 12 to 18 years) were 8:30 AM to 4:00 PM. Children were required to use electronic devices for virtual learning 5 days a week and further hours after school to complete assignments. With COVID-19 restrictions in place, typical weekends for children also required extensive stay at home, with limited social interactions.

Procedures

University of Houston Near Work, Environment, Activity, and Refraction Survey

Parents completed the University of Houston Near work, Environment, Activity, and Refraction Survey (Appendix 1, available at http://links.lww.com/OPX/A558).[26,35] Children answered the questionnaire with their parents, when possible. Classification of refractive status as myopic or nonmyopic was based on the questionnaire using an indirect method, with a series of questions about the use of eyeglasses and age at first dispensing.[36] This method has been shown to have reasonable sensitivity and specificity (0.76 and 0.74, respectively) for determining whether a participant is myopic.Refractive status was further confirmed by observing the refractive correction, if any, being worn by the child, when study material was dispensed.

In the questionnaire, parents were asked to estimate daily time spent in various activities for weekdays (Monday to Friday) and weekend days (Saturday to Sunday). Sleep duration was estimated for weeknights (Sunday to Thursday nights) and weekend nights (Friday to Saturday nights). Duration of near viewing was calculated by adding the estimated hours spent reading printed material, writing, drawing, painting, crafting, and using handheld electronic devices. Duration of intermediate viewing was calculated by adding the estimated hours spent using computers and playing board games or cards. Subjective diopter hours were calculated from questionnaire data using Equation 1. Activities performed at the closest distance were weighted times 3, as previous studies show that these activities are performed at distances from approximately 25 to 45 cm, or a mean dioptric demand of approximately 3 D.[26,31] Activities performed at an intermediate distance were weighted times 1.5, as these activities are generally performed at distances of 60 to 100 cm, or a mean dioptric demand of approximately 1.5 D.[26] Weekday and weekend diopter hours was calculated separately.

$$\begin{aligned}\text{Subjective diopter hours} = {} & [3 \times (\text{hours reading print} + \text{hours drawing, painting, writing} \\ & + \text{hours using handheld devices})] + [1.5 \times (\text{hours using computers} \\ & + \text{hours playing board games or cards})].\end{aligned}$$

Equation 1

Other metrics derived from the questionnaire included electronic device use, time outdoors, and sleep duration. Electronic device use included handheld devices, computers, and television. Time outdoors included outdoor physical and leisure activity and driving or riding in a car.

Clouclip

This study used 19 Clouclips (Glasson Technology Co. Ltd.) for objective measurement of viewing distance and ambient illuminance. The Clouclip is a small, lightweight range-finding device that is mounted on the right temple of the spectacle frame (Fig. 1A). With the built-in infrared tracking beam and integrated chips, distance is measured every 5 seconds, and ambient illuminance is measured every 2 minutes (Wen L, et al. IOVS 2016;57:ARVO E-Abstract 2491). The infrared tracking beam has a diameter of 25° and is directed 10° downward. The reported measurement range of Clouclip is 5 to 120 cm for distance and 1 to 65,336 lux for ambient illuminance. The built-in triaxis accelerometer (*x*, *y*, and *z* axes) detects the status of wearing or not wearing. The Clouclip goes into sleep mode if no movement is detected for 40 seconds. During sleep mode, no data are recorded for at least 2 minutes and until motion is detected again. Data are retrieved using Bluetooth and the smartphone application. The Clouclip requires nightly charging; once fully charged, data can be collected for a full day. The device can store up to 8 days of data. The Clouclip devices were validated for distance and illuminance, as previously described.[31] Previous studies have shown good utility of the Clouclip in objective measurement of working distance and light exposure.[37–39]

FIGURE 1. Wearable sensors used in this study. (A) Clouclip device fitted to the right temple of a spectacle frame in a myopic participant. (B) Actiwatch Spectrum Plus.

Clouclip data were analyzed using a custom MATLAB program (The MathWorks Inc., Natick, MA). For each child, days with ≥8 hours of data during wake time were considered valid, and at least three valid weekdays and one valid weekend day were required for the child to be included in the analysis. Clouclip-recorded viewing distances were classified as near (10 to <60 cm), intermediate (60 to <100 cm), or far (≥100 cm). The following metrics were calculated from distance data for weekdays and weekend days: (1) duration of near viewing; (2) duration of intermediate viewing; (3) duration of near + intermediate viewing; (4) frequency, duration, and distance of short-duration near-viewing episodes (continuous near viewing for >1 minute with no interruption >20 seconds); (5) frequency, duration, and distance of long-duration near-viewing episodes (near viewing >30 minutes with no interruption >60 seconds); (6) duration of viewing in 10-cm bins from 10 to <100 cm; and (7) objective diopter hours (Equation 2).

$$\text{Objective diopter hours} = [3 \times (\text{hours viewing 0.1 to} <0.6 \text{ m})] + [1.5 \times (\text{hours viewing 0.6 to} <1.0 \text{ m})]. \quad \text{Equation 2}$$

Time outdoors was defined as the duration exposed to illuminance ≥1000 lux, criterion used in previous studies.[23,25,27] Clouclip-recorded light exposure was analyzed for (1) daily white light exposure (in lux); (2) duration in various light intensities, including indoors (<1000 lux) and outdoors (≥1000, >2000, >3000, and >5000 lux); and (3) number of transitions from indoor to outdoor light.

Near and intermediate viewing, light exposure, and time outdoors were further analyzed for specific times of the day on school days/nights: (1) school period (Monday to Friday, 8:30 AM to 4:00 PM), (2) school evening (Monday to Friday, 4:00 PM to 8:00 PM), and (3) evenings (all days, 8:00 PM to bedtime). Myopic and nonmyopic children may have different bedtimes and, subsequently, may spend different amounts of time doing near work. The evening time from 8:00 PM to bedtime allowed for the assessment of these potential differences.

Actiwatch

Twenty Actiwatches (Actiwatch Spectrum Plus; Philips Respironics) were used for objective measurement of physical activity and sleep duration. The Actiwatch is a wrist-worn actigraph device (Fig. 1B) that records ambient illuminance and activity at 32 Hz. It is lightweight (31 g) and waterproof for up to 30 minutes, allowing continuous wear. Ambient illuminance measurement rangesare 380 to 750 nm and 0.1 to 35,000 lux for white light. Activity is measured using a solid-state micro-electro-mechanical systems-type accelerometer and expressed in counts per minute. The Actiwatch can store data for up to 50 days when it is fully charged and configured to average over 1-minute epochs. The Actiwatch contains an "off-wrist" sensor to monitor wear compliance. All children and parents were instructed to ensure the light sensors on the watch were not obstructed by clothing and to record instances on daily log when the watch was removed. Actiwatches were tested for illuminance measurement as previously described.[23]

Actiwatch data were retrieved and analyzed using the Actiware software (Actiware Version 6.0.8; Philips Respironics). Physical activities (in counts per minute) for the wake period and sleep duration were determined for weekdays and weekend days.

Data Analysis

Each metric derived from the questionnaire, Clouclip, and Actiwatch was determined for weekdays and weekend days separately. From these values, a "mean daily" value was calculated for each metric using Equation 3.

$$\text{Mean daily} = [(\text{average weekday} \times 5) + (\text{average weekend}) \times 2]/7. \quad \text{Equation 3}$$

Statistical analysis was performed in SPSS 22.0 (IBM Corp., Armonk, NY). Data are presented at mean ± standard error, unless otherwise stated. Paired *t* tests were used to compare children's demographics between refractive error groups. Repeated-measures analyses of variance were performed to compare near work and light

TABLE 1. Clouclip-measured near-viewing and light exposure metrics, Actiwatch-measured physical activity and sleep duration, and questionnaire-measured electronic device use

Parameter	Weekday	Weekend	Mean daily	Day of the week	Refractive error group	Day of the week × refractive error group
Duration of near viewing, measured with Clouclip (h)						
Nonmyopes	6.5 ± 0.5	5.2 ± 0.5	6.2 ± 0.5			
Myopes	8.0 ± 0.5	5.8 ± 0.4	7.4 ± 0.4	<.001*	.07	.13
Total	7.4 ± 0.3	5.6 ± 0.3	6.9 ± 0.3			
Duration of intermediate viewing, measured with Clouclip (h)						
Nonmyopes	1.1 ± 0.4	0.7 ± 0.2	1.0 ± 0.2			
Myopes	1.5 ± 0.3	1.3 ± 0.2	1.4 ± 0.3	.09	.17	.63
Total	1.3 ± 0.2	1.1 ± 0.1	1.3 ± 0.2			
Duration of near + intermediate viewing, measured with Clouclip (h)						
Nonmyopes	7.6 ± 0.5	6.0 ± 0.5	7.1 ± 0.5			
Myopes	9.4 ± 0.4	7.1 ± 0.4	8.8 ± 0.3	<.001*	.008†	.29
Total	8.8 ± 0.3	6.7 ± 0.3	8.1 ± 0.3			
Objective diopter hours, calculated using Clouclip data (dh)						
Nonmyopes	21.2 ± 1.4	23.0 ± 1.9	21.8 ± 1.5			
Myopes	26.1 ± 1.1	26.8 ± 1.5	26.3 ± 1.0	.18	.03†	.55
Total	24.3 ± 0.9	25.4 ± 1.2	24.6 ± 0.9			
Frequency of short-duration near-viewing episodes, measured with Clouclip						
Nonmyopes	60.8 ± 4.5	54.0 ± 4.6	58.9 ± 4.1			
Myopes	62.4 ± 2.0	54.4 ± 2.3	60.1 ± 1.8	.002†	.80	.78
Total	61.8 ± 2.1	54.3 ± 2.2	59.7 ± 1.9			
Duration of short-duration near-viewing episodes, measured with Clouclip (min)						
Nonmyopes	6.7 ± 0.8	5.5 ± 0.5	6.4 ± 0.6			
Myopes	8.2 ± 0.6	7.0 ± 0.9	7.9 ± 0.6	.06	.12	.98
Total	7.7 ± 0.5	6.4 ± 0.6	7.3 ± 0.4			
Distance of short-duration near-viewing episodes, measured with Clouclip (cm)						
Nonmyopes	31.2 ± 1.0	29.7 ± 1.0	30.7 ± 0.8			
Myopes	31.9 ± 1.1	30.9 ± 1.2	31.6 ± 1.0	.10	.51	.76
Total	31.6 ± 0.8	30.4 ± 0.8	31.3 ± 0.7			
Frequency of long-duration near-viewing episodes, measured with Clouclip						
Nonmyopes	3.2 ± 0.4	2.3 ± 0.5	2.9 ± 0.4			
Myopes	3.9 ± 0.4	2.3 ± 0.4	3.4 ± 0.4	<.001*	.51	.16
Total	3.6 ± 0.3	2.3 ± 0.3	3.2 ± 0.3			
Duration of long-duration near-viewing episodes, measured with Clouclip (min)						
Nonmyopes	61.5 ± 4.6	58.4 ± 3.7	61.8 ± 4.1			
Myopes	68.5 ± 3.7	65.0 ± 3.7	68.6 ± 3.0	.21	.14	.97
Total	65.9 ± 2.9	62.4 ± 2.7	66.0 ± 2.5			
Distance of long-duration near-viewing episodes, measured with Clouclip (cm)						
Nonmyopes	32.7 ± 1.0	30.0 ± 1.4	31.7 ± 1.0			
Myopes	33.4 ± 1.0	32.6 ± 1.6	33.3 ± 1.1	.13	.26	.49
Total	33.1 ± 0.7	31.6 ± 1.1	32.7 ± 0.8			
Daily light exposure, measured with Clouclip (lux)						
Nonmyopes	277 ± 40	620 ± 134	375 ± 253			
Myopes	146 ± 31	267 ± 40	180 ± 174	.008†	.01†	.19
Total	195 ± 26	399 ± 26	253 ± 36			

TABLE 1. *Continued*

Parameter	Weekday	Weekend	Mean daily	Day of the week	Refractive error group	Day of the week × refractive error group
Time outdoors, measured with Clouclip (h)						
Nonmyopes	0.6 ± 0.1	1.4 ± 0.3	0.6 ± 0.1			
Myopes	0.3 ± 0.1	0.6 ± 0.2	0.3 ± 0.1	.007†	.02†	.20
Total	0.4 ± 0.1	0.9 ± 0.2	0.5 ± 0.1			
No. transitions from indoors to outdoors, measured with Clouclip						
Nonmyopes	4.2 ± 0.1	8.4 ± 2.1	5.4 ± 1.0			
Myopes	3.7 ± 0.8	4.4 ± 0.1	3.9 ± 0.7	.01†	.12	.08
Total	3.9 ± 0.6	5.9 ± 1.0	4.5 ± 0.6			
Physical activity, measured with Actiwatch (cpm)						
Nonmyopes	255 ± 26	260 ± 23	262 ± 22			
Myopes	256 ± 21	295 ± 21	265 ± 20	.05†	.51	.25
Total	255 ± 16	282 ± 16	264 ± 15			
Electronic device use, measured with questionnaire (h)						
Nonmyopes	12.0 ± 1.3	10.0 ± 1.3	11.4 ± 1.2			
Myopes	12.5 ± 1.0	11.6 ± 1.0	12.2 ± 1.9	.008†	.50	.31
Total	12.3 ± 0.8	11.0 ± 0.8	12.0 ± 0.7			
Sleep duration, measured with Actiwatch (h)						
Nonmyopes	8.1 ± 0.3	8.8 ± 0.3	8.4 ± 0.3			
Myopes	7.8 ± 0.3	9.0 ± 0.2	8.2 ± 0.2	<.001*	.92	.17
Total	7.9 ± 0.2	8.9 ± 0.2	8.3 ± 0.1			

P values are shown for repeated-measures analysis of variance. *Significance at $P < .001$. †Significance at $P < .05$. dh = diopter hours.

exposure metrics, physical activity, sleep duration, and electronic device use, with day of the week (weekday or weekend) as a within-subject factor and refractive error group (myopic or nonmyopic) as a between-subject factor. Subjective and objective measures were compared with each other using repeated-measures analysis of variance with day of the week and method of collection (objective or subjective) as within-subject factors. Bonferroni-corrected *post hoc* comparisons were carried out where indicated; Bonferroni-adjusted significance was set at $P < .05$.

RESULTS

Fifty-eight children enrolled in the study. Clouclip data were not valid for 18 children; some children were not compliant with wearing the device, and others had less than 8 hours of valid data each day. No differences were found in terms of refractive error type or sex between the retained and the excluded subjects. Eight nonmyopes and 10 myopes were excluded. The χ^2 test of distribution showed that the proportion of children who were retained and who were excluded did not differ by the type of the refraction (χ^2_1 [n = 58] = 0.24, $P = .62$). Likewise, 10 boys and 8 girls were excluded, and the χ^2 test of distribution showed that the proportion of children who were retained and who were excluded did not differ by sex (χ^2_1 [n = 58] = 0.32, $P = .57$).

Data for 40 children (25 myopes and 15 nonmyopes) with valid data are considered further. Mean ± standard deviation age was 14.6 ± 0.4 years (range, 10 to 18 years). Myopic and nonmyopic groups were of similar age ($P = .26$), and male and female participants were of similar age ($P = .64$). Parent-reported races of the children were Asian (n = 22), White (n = 14), African American (n = 2), American Indian or Alaskan native (n = 1), and other (n = 1). There were 37 non-Hispanic and 3 Hispanic children. The χ^2 test of distribution showed the proportion of children who were myopic differed by ethnicity; Asian children were more likely to be myopic compared with non-Asian children (χ^2_1 [n = 40] = 4.43, $P = .03$). Two children (both nonmyopes) reported attending in-person classes during the study week, and the rest of the children (95%) attended virtual online schooling.

Clouclip-measured near-viewing and light exposure metrics, Actiwatch-measured physical activity and sleep duration, and questionnaire-measured electronic device use are summarized in Table 1 for weekdays, weekends, and mean daily (weighted mean across the week using Equation 3).

Near Work

The mean ± standard deviation valid days of Clouclip wear was 6.6 ± 0.7 (range, 4 to 7). Average daily Clouclip wear times for weekday and weekend days were 15.1 ± 0.2 and 13.7 ± 1.6 hours, respectively, with a mean daily wear time of 14.7 ± 0.2 hours. Mean hours of wear per day was similar between refractive error groups ($P = .10$).

Clouclip-measured mean daily duration of viewing from 10 to >100 cm in 10-cm bins and ≥100 cm by refractive error group is shown in Fig. 2. Although myopic children tended to have more time

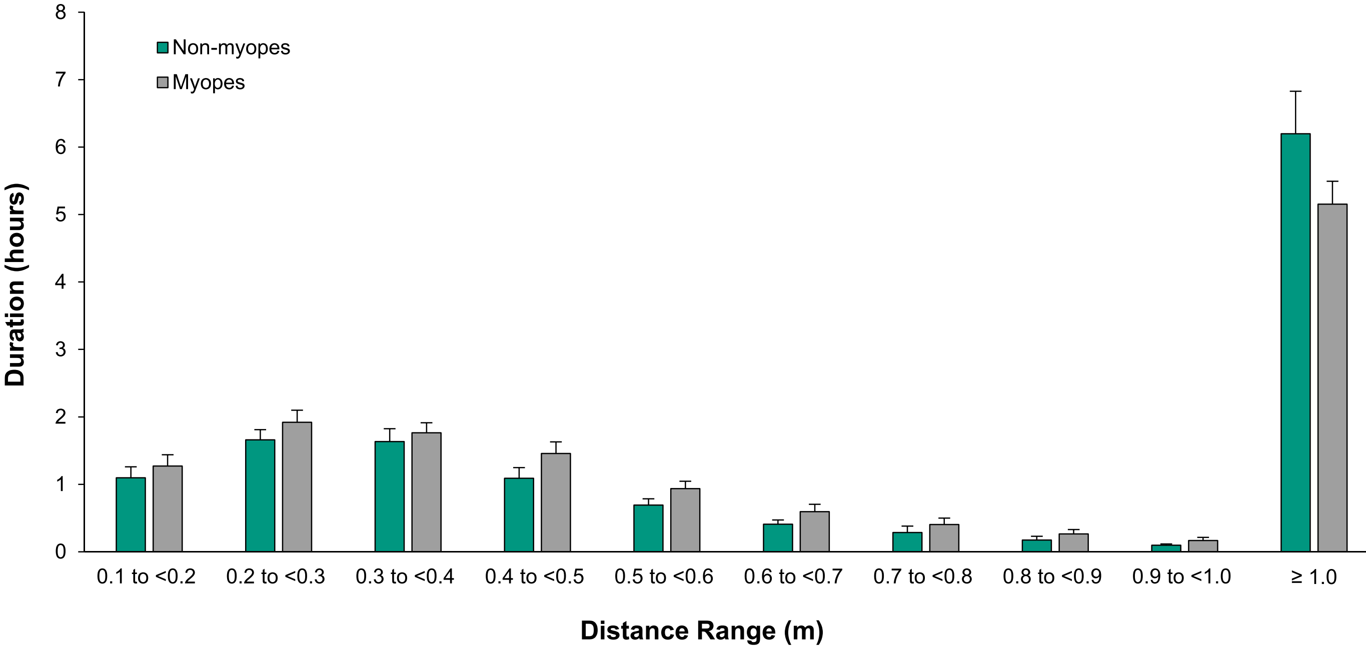

FIGURE 2. Mean daily duration of viewing distances in 10-cm bins from 0.1 to ≥1.0 m for nonmyopes (seafoam green) and myopes (gray); error bars represent standard error of the mean.

spent in each 10-cm viewing bin from 10 to <100 cm and less time in far viewing (≥100 cm), differences between refractive error groups by viewing bin were not significantly different ($P > .05$ for all bins).

Near, intermediate, and near + intermediate viewing for weekdays by refractive error group is shown in Fig. 3. Mean daily duration of near viewing (10 to <60 cm) was 6.9 ± 0.3 hours and differed with day of the week ($P < .001$), but not by refractive error group ($P = .07$). Duration of near viewing was 1.8 hours greater on weekdays compared with weekend days. Mean daily duration of intermediate viewing (60 to <100 cm) was 1.3 ± 0.2 hours and did not vary by day of the week ($P = .09$) or by refractive error group ($P = .16$). However, mean daily duration of near + intermediate viewing (10 to <100 cm) significantly differed by day of the week ($P < .001$) and by refractive group ($P = .008$). Duration of near + intermediate viewing was greater for myopes (8.3 ± 0.3 hours) than nonmyopes (6.8 ± 0.4 hours), and greater on weekdays (8.5 ± 0.3 hours) than weekend days (6.5 ± 0.3 hours).

Mean daily objective diopter hours were 24.6 ± 0.9. Objective diopter hours did not differ by day of the week ($P = .18$) but were significantly greater for myopes (26.4 ± 1.2 diopter hours) than nonmyopes (22.1 ± 1.5 diopter hours, $P = .03$).

Daily episodes of short-duration and long-duration near viewing were quantified in terms of frequency, duration, and viewing distance. For short-duration near viewing, children averaged 60.0 ± 1.9 episodes of 7.3 ± 0.4 minutes at a distance of 31.3 ± 0.7 cm per day. Frequency of episodes of near work was greater on weekdays compared with weekend days ($P < .002$) and did not differ between refractive error groups ($P = .80$). Mean duration and distance did not vary by day of the week or refractive group ($P > .05$ for all).

For long-duration near viewing, children averaged 3.2 ± 0.3 episodes of 66.0 ± 2.5 minutes at a distance of 32.7 ± 0.8 cm per day. Frequency of long-duration near-viewing episodes was greater on weekdays compared with weekend days ($P < .001$). There were no significant differences in frequency, duration, or distance of long-duration near viewing by refractive error group ($P > .05$ for all).

Light Exposure

Clouclip-measured daily white light exposure was 253 ± 36 lux and differed significantly by day of the week ($P = .008$) and refractive error group ($P = .01$). Daily white light exposure was less for weekdays (211 ± 25 lux) than weekend days (443 ± 85 lux) and less for myopes (180 ± 35 lux) than for nonmyopes (375 ± 65 lux). Time outdoors per day (time exposed to ≥1000 lux) was 0.5 ± 0.1 hours. Time outdoors was less for weekdays (0.4 ± 0.1 hours) than for weekends (1.0 ± 0.2 hours, $P = .007$) and less for myopes (0.4 ± 0.1 hours) than for nonmyopes (1.0 ± 0.2 hours, $P = .02$).

The average daily number of transitions from indoor to outdoor light was 4.5 ± 0.6 per day (range, 0 to 29 per day). There were significantly more transitions on weekend days than weekdays ($P = .01$), with no differences between refractive error groups ($P = .12$).

Mean duration exposed to indoor light (1 to <1000 lux) and different levels of outdoor light intensities (≥1000, >2000, >3000, and >5000 lux) by day of the week and refractive error group are shown in Table 2. Indoor time was significantly greater on weekdays (12.7 ± 0.2 hours) compared with weekend days (11.0 ± 0.3 hours, $P < .0001$). Myopes (12.6 ± 0.3 hours) spent on average 1.4 ± 0.4 hours per day of greater duration indoors compared with nonmyopes (11.1 ± 0.3 hours, $P = .002$). Duration of outdoor light exposure (≥1000 lux) was greater on weekend days (1.0 ± 0.2 hours) than weekdays (0.4 ± 0.1 hours, $P = .007$). For all thresholds of outdoor light levels, myopic children spent less duration compared with nonmyopic children ($P < .05$ for all).

Analysis by Time of Day

Near and intermediate viewing, light exposure, and time outdoors, analyzed by period of the day, are shown in Table 3. There were no significant differences in near viewing or intermediate viewing for the

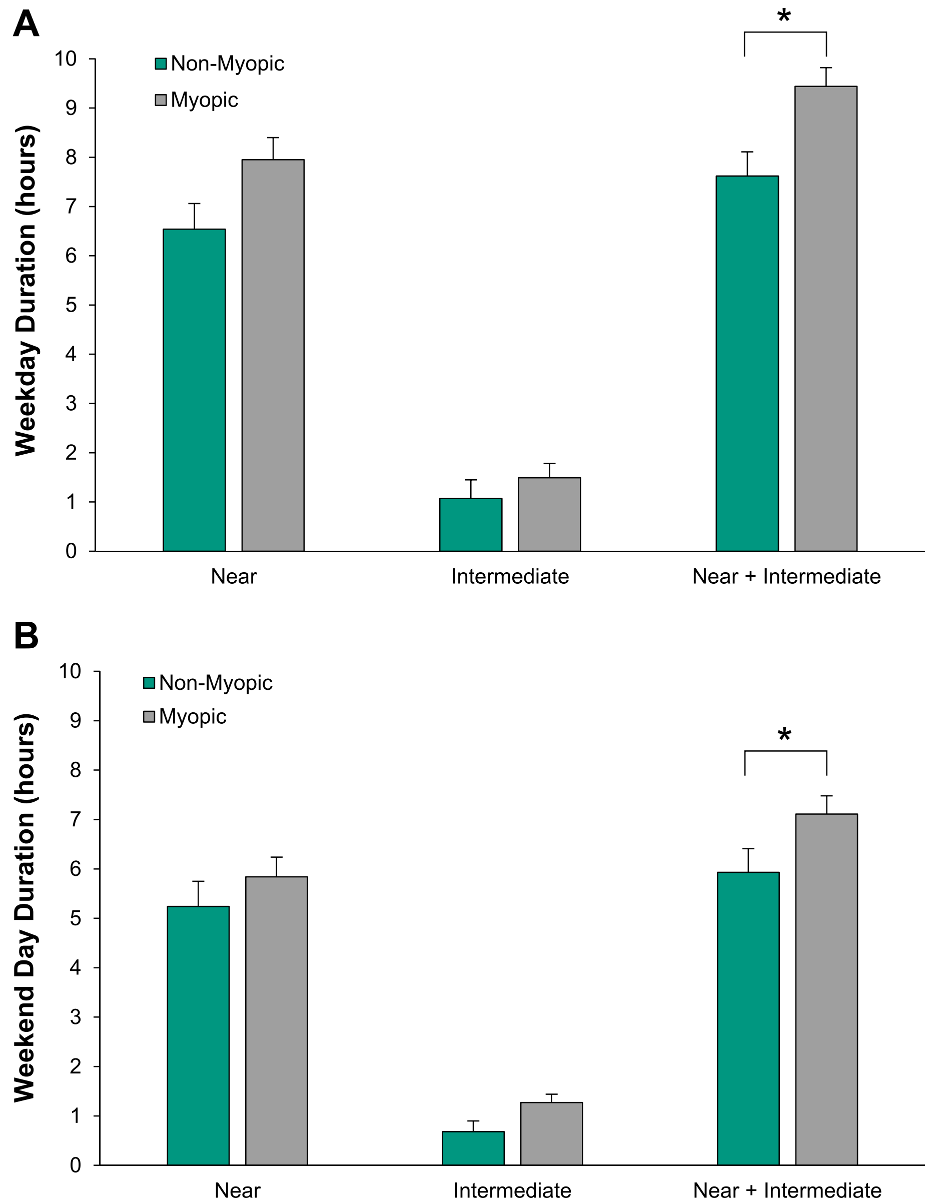

FIGURE 3. Daily duration (in hours) of near (10 to <60 cm), intermediate (60 to <100 cm), and near + intermediate viewing (10 to <100 cm) on weekdays (A) and weekend days (B) for nonmyopes (seafoam) and myopes (gray); error bars represent standard error of the mean.

school period (Monday to Friday, 8:30 AM to 4:00 PM), school evening (Monday to Friday, 4:00 PM to 8:00 PM), or evenings (all 7 days, 8:00 PM until bedtime) between myopes and nonmyopes. However, near + intermediate viewing duration was significantly longer for myopes compared with nonmyopes ($P = .01$). Near-viewing duration and intermediate-viewing duration were significantly greater during school period compared with after-school evening ($P < .01$ for both near and intermediate work) and evenings ($P < .0001$ for both near and intermediate work). Light exposure was significantly different between the three time periods ($P < .0001$) and by refractive error groups ($P = .03$), with a significant interaction between time period and refractive error group ($P = .005$). Pairwise comparisons showed that light exposure during the school period was significantly lower for myopes (178 ± 172 lux) than nonmyopes (421 ± 336 lux, $P = .004$). Similarly, time outdoors was significantly different between time periods ($P < .0001$) and by refractive error groups ($P = .02$), with a significant interaction between time period and refractive error group ($P = .001$). Pairwise comparisons showed that time outdoors during the school period was significantly lower for myopes (0.2 ± 0.1 hours) than nonmyopes (0.5 ± 0.1 hours, $P = .005$).

Sleep

Actiwatch-measured daily sleep duration was 8.2 ± 0.2 hours. Sleep duration varied by day of the week ($P < .001$) but not refractive error group ($P = .90$). Sleep duration was longer on weekend nights (8.9 ± 0.2 hours) than weeknights (7.9 ± 0.2 hours).

Electronic Device Use

Electronic device use was calculated from the questionnaire as time spent using handheld electronics, computers, and TV. Estimated hours of electronic device use across all children was 11.9 ± 0.7 hours

TABLE 2. Clouclip-measured average duration (in hours) exposed to indoor (1 to <1000 lux) and four levels of outdoor photopic lux (≥1000, >2000, >3000, and >5000 lux) by day of the week and refractive error group

	Weekday	Weekend	Day of week	Refractive group	Day of week × refractive group
Indoors, exposed to 1 to <1000 lux (h)					
Nonmyopes	6.6 ± 0.7	6.3 ± 0.6	<.0001*	.002†	.51
Myopes	6.4 ± 0.5	6.7 ± 0.5			
Outdoor photopic, exposed to ≥1000 lux (h)					
Nonmyopes	0.6 ± 0.1	1.4 ± 0.3	.007†	.02†	.20
Myopes	0.3 ± 0.1	0.6 ± 0.2			
Outdoor photopic, exposed to >2000 lux (h)					
Nonmyopes	0.4 ± 0.7	1.0 ± 0.2	.008†	.006†	.27
Myopes	0.1 ± 0.1	0.4 ± 0.2			
Outdoor photopic, exposed to >3000 lux (h)					
Nonmyopes	0.3 ± 0.1	0.7 ± 0.2	.02†	.008†	.43
Myopes	0.1 ± 0.04	0.3 ± 0.1			
Outdoor photopic, exposed to >5000 lux (h)					
Nonmyopes	0.2 ± 0.04	0.4 ± 0.1	.03†	.01†	.52
Myopes	0.04 ± 0.03	0.2 ± 0.1			

P values are shown for repeated-measures analysis of variance. *Significance at $P < .001$. †Significance at $P < .05$.

per day. Duration varied with day of the week ($P = .01$) but not by refractive error group ($P = .50$). Electronic device use was 1.5 hours per day greater on weekdays than weekend days.

Subjective versus Objective Data

Near work, time outdoors, and sleep duration were quantified both subjectively from the questionnaire and objectively by the Clouclip and Actiwatch (Fig. 4). Near-viewing duration was significantly greater as measured with the Clouclip than estimated in the questionnaire for weekdays ($P = .04$), although the methods were similar on weekend days ($P = .17$). Clouclip-measured near-viewing duration was greater on weekdays than weekend days ($P < .001$), whereas weekday and weekend day durations were similar according to the questionnaire ($P = .06$). Similarly, subjective diopter hours was greater than objective diopter hours for weekdays ($P = .02$) but not for weekend days ($P = .57$).

Time outdoors was significantly greater according to the questionnaire than measured objectively with the Clouclip for weekdays ($P < .001$) and weekend days ($P < .001$). For both methods, time outdoors was significantly greater on weekend days than weekdays ($P < .05$ for both).

Sleep duration was significantly greater measured objectively by the Actiwatch than subjectively with the questionnaire for weeknights ($P = .01$) but not for weekend nights ($P = .81$). For both methods, sleep duration was significantly greater for weekend nights than weeknights ($P < .001$ for both).

DISCUSSION

In this study, we quantified behaviors using subjective and objective methods to obtain a comprehensive assessment of the visual environment in myopic and nonmyopic schoolchildren in Houston, TX. Using objective wearable sensors, findings show that myopic children had longer daily near + intermediate (10 to <100 cm) viewing duration, lower light exposure, and less time in high-intensity outdoor light (>1000 lux) compared with nonmyopic children.

Estimates of electronic device use were approximately 12 hours per day. Of importance to note, this study was conducted between December 2020 and May 2021. During this time, most children were carrying out their schooling virtually because of COVID-19 social restrictions. Indeed, 95% of the children in the current study were in virtual school, and those who went in-person primarily worked on a computer while at school. The COVID-19 pandemic is an unprecedented event and likely affected all aspects of children's lives. We believe that both myopic and nonmyopic children were equally affected, and therefore, findings of this study are valuable for two reasons: (1) behaviors were quantified during a pandemic, and (2) behaviors between myopic and nonmyopic children were collected and compared during the same time period.

Objectively measured viewing distances with the Clouclip showed that children performed a significantly greater duration of near viewing (10 to 60 cm) during weekdays compared with weekend days, likely because of time spent in class and completing homework on weekdays. Near + intermediate viewing (10 to 100 cm) was significantly greater for myopic children compared with nonmyopic children. We included near + intermediate viewing as an important outcome measure because, subjectively, there is overlap in some activities in whether they belong to the near or intermediate category. For example, hours using a computer is considered as intermediate viewing from the survey. However, it is likely that many children actually view the computer at closer distance (<60 cm). Therefore, to be able to incorporate this overlapping range of near and intermediate activities, durations of near and intermediate viewing were combined for analyses along with individual analyses. These objective data confirm previously reported subjective data showing that myopic children perform more near work than nonmyopic children.[7–9,11] Previous studies show that increased

TABLE 3. Clouclip-measured near, intermediate, and near + intermediate viewing, light exposure, and time outdoors, analyzed for three periods of the day (school, after school, and nighttime) for myopes and nonmyopes

	Nonmyopes	Myopes	P
Near viewing (h)			.07
School period	3.3 ± 0.3	4.1 ± 0.2	
After-school period	1.5 ± 0.1	1.8 ± 0.1	
Nighttime	1.7 ± 0.3	1.8 ± 0.2	
Intermediate viewing (h)			.38
School period	0.6 ± 0.2	0.8 ± 0.2	
After-schoolperiod	0.3 ± 0.1	0.3 ± 0.1	
Nighttime	0.2 ± 0.1	0.3 ± 0.1	
Near + intermediate viewing (h)			.01*
School period	3.8 ± 0.3	4.8 ± 0.2	
After-school period	1.7 ± 0.2	2.2 ± 0.1	
Nighttime	1.9 ± 0.3	2.1 ± 0.2	
Light exposure (lux)			.03*
School period	421 ± 87	178 ± 34	
After-school period	267 ± 74	181 ± 36	
Nighttime	22 ± 2	36 ± 7	
Time outdoors (h)			.02*
School period	0.5 ± 0.1	0.2 ± 0.1	
After-school period	0.1 ± 0.0	0.1 ± 0.0	
Nighttime	0.0 ± 0.0	0.0 ± 0.0	

P values are shown for main effects of refractive error group. *Significance at $P < .05$.

daily near work and shorter working distance are associated with increased risk of myopia.[8,40,41] In a study by Ip et al.[42] using questionnaires, shorter working distances (<30 cm) and continuous reading (>30 minutes) increased the odds of myopia by 2.5 and 1.5 times, respectively. Intense near work and taking fewer viewing breaks during near work were associated with significant increased risk of myopia.[11] The Clouclip records viewing distance continuously at 0.2 Hz, providing the opportunity to study temporal properties of viewing behavior, such as episodes of short-duration and long-duration near viewing, which are novel metrics that may be relevant to myopia. Here, the frequency, duration, and absolute viewing distance of daily near episodes (10 to 60 cm) were determined. No differences were observed in the frequency, duration, or distance of short- or long-duration near-viewing episodes between refractive error groups. Another study using the Clouclip in fifth-grade children in China also showed no difference in continuous near work between refractive error groups.[38]

In accordance with previous studies,[27] objectively measured light exposure differed significantly between myopic and nonmyopic children in this study. The average daily white light exposure was significantly lower in myopes (180 lux) than nonmyopes (375 lux). Interestingly, Wen et al.[37] also used the Clouclip for 1 week, and the reported mean daily light exposures in nonmyopic and myopic fifth-grade children were 739 and 832 lux, respectively, with no significant differences by refractive group. The very low daily white light exposure found in the current study could be due to the impact of COVID-related social restrictions, with most children staying indoors during the day. Other differences between studies are the age range of the children included, as well as geographic location and, potentially, different seasons in which measurements were captured. In addition, the previous study included only data collected between 7:00 AM to 8:00 PM, whereas in this study, data were collected from wake time to bedtime, and therefore, more dim nighttime illumination would have been included, bringing down the daily mean.

Several behavioral studies in children have shown the protective effects of light exposure and outdoor time against the onset and progression of myopia.[14,15,43] Previous studies have reported that myopic children spend less time outdoors than nonmyopicchildren, as determined using parent questionnaires[12,13,44] and using objective sensors.[23,27,45] Here, myopic children spent approximately half as much time exposed to outdoor bright light compared with nonmyopes on both weekdays and weekend days, as measured objectively with the Clouclip. Surprisingly, time outdoors averaged only 24 minutes on weekdays and 54 minutes on weekend days, significantly less time outdoors than we have found in previous studies. For example, in 5- to 10-year-olds, children spent approximately 72 minutes outdoors per day during a similar season, as measured with an Actiwatch.[28] We speculate that this difference can likely be attributed to the tendency for children to stay home during the COVID-19 pandemic, as many after-school activities were canceled, as well as the older age range of the current population and heavier academic workload experienced by these children. Despite changes in lifestyle due to the pandemic, the observed difference in time outdoors between refractive error groups is consistent with the findings of Read et al.,[27] who reported 36 minutes less time outdoors for myopic children compared with nonmyopic children, as measured objectively using Actiwatch in Australian children aged 10 to 15 years.In addition, Read et al.[27] found that increased mean daily exposure to >3000 lux was associated with slower axial eye elongation over an 18-month period. Clinical trials encouraging outdoor exposure or implementing additional outdoor time during school have shown decreased incidence of myopia in children.[15,46] Thus, lower light exposure in myopic children, as observed here, may have an effect on myopia progression in already myopic children. Similarly, the very low light exposure experienced by nonmyopic children, compared with previous studies carried out when there was nopandemic, may result in increased myopia prevalence in the future.

The Actiwatch has been extensively used in children and adults for myopia and circadian rhythm studies.[23,26,27]Although the light level measured with wrist-worn device has been found to correlate significantly with illuminance at eye level ($r = 0.76$),[47] the Actiwatch is sensitive to orientation[48] and obstruction by the wearer's sleeve, which may contribute to increased variability in Actiwatch-measured light exposure. The Clouclip is mounted to spectacles at eye level with the light sensor directed approximately along the visual axis, which may provide a more contextual measurement of light reaching the eye.

Subjective estimates of near work were similar to objective measurements, whereas time outdoors was significantly overestimated compared with objective measurements. Quantification of outdoor time and near work using questionnaires has limited reliability and accuracy[22] and is subject to recall and parental biases.[20,21] Using questionnaires to gather near-work data fails to capture temporal properties of near viewing, such as frequent changes in viewing distance and duration and absolute distance of near-viewing episodes. Quantification of near work using accommodation-weighted

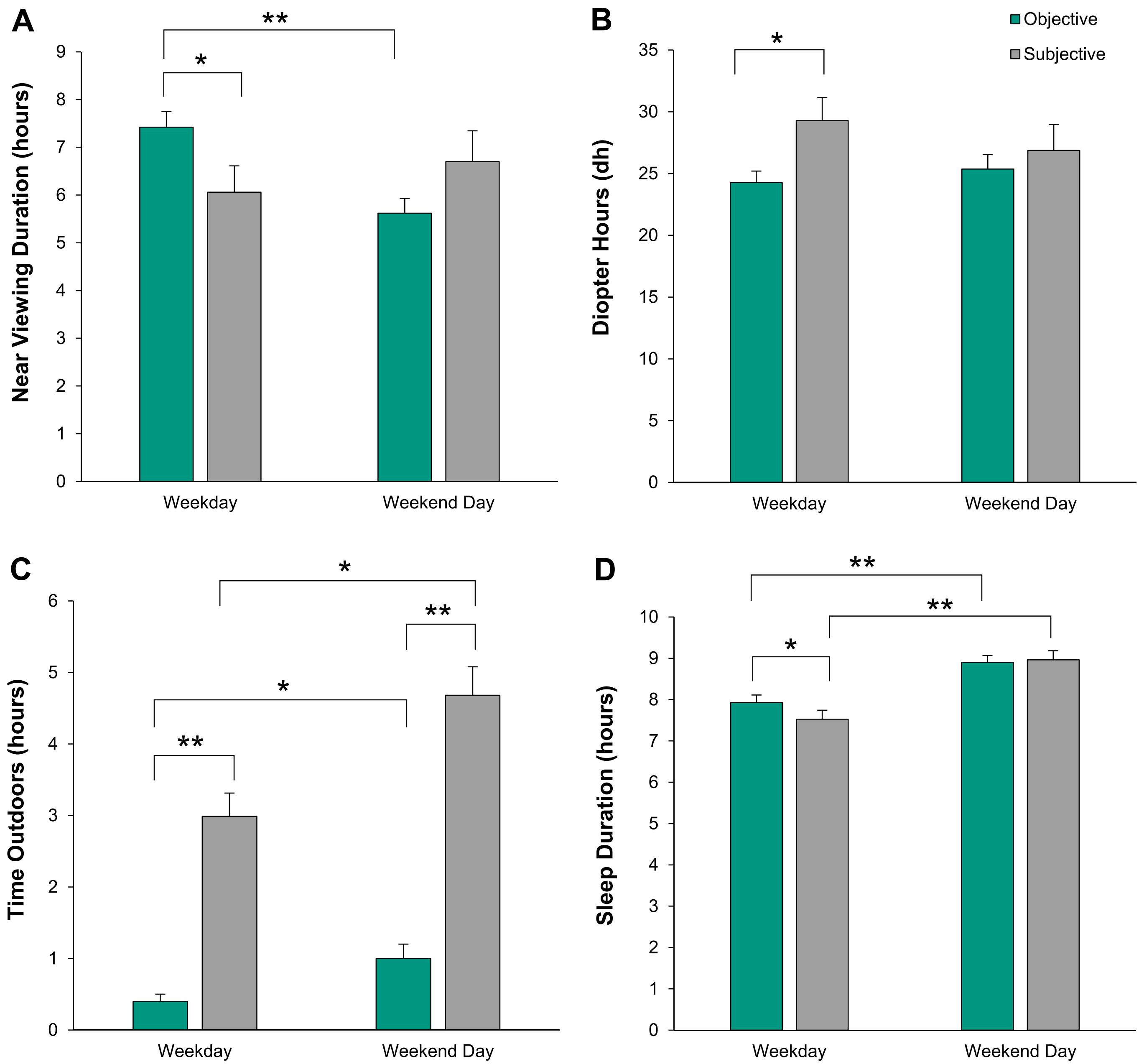

FIGURE 4. Objective (seafoam green) and subjective (gray) measurements of daily near-viewing duration (in hours; A), diopter hours (dh; B), time outdoors (in hours; C), and sleep duration (in hours; D) for weekdays and weekend days. *Significance at $P < .05$. **Significance at $P < .001$.

metric such as diopter hours is often limited by intersubject differences in absolute viewing distance and accommodative demand for various near tasks.[49] As such, the use of diopter hours to subjectively quantify near-work load has largely been abandoned in recent literature. However, objective measures of near work provide a precise measure of viewing distance that can be translated into accommodative demand. Therefore, diopter hours is a relevant metric when considering objective data. Based on the age and grade of the children, the accommodative demand for near work also changes. A study in fifth- and sixth-grade children reported that the modern classroom environments require a relatively high level of visual acuity, contrast demand, and sustained accommodative-convergence responses, which vary based on different classroom tasks.[50] Thus, objective quantification of the visual behaviors done in the habitual visual environment provides a more relevant quantification of near work and light exposure for myopia-related studies than subjective questionnaires.

Studies in animal models of myopia have highlighted a role of temporal patterns of myopiogenic stimuli.[51,52] For example, only 45 minutes of unrestricted vision protects from compensating axial elongation in tree shrews reared with negative lenses.[51] With the evidence from animal studies, inferences regarding the importance of taking viewing breaks during intense near work could be made.[51,52] Quantification of near-viewing episodes in children's habitual environment for duration, distance, and frequency provides a method to assess metrics pertinent to myopia studies. Likewise, pattern of light exposure and transitions from indoor to outdoor light levels might be important factor to consider along with absolute light exposure. Similarly, continuous objective measurement of light exposure has the capability to quantify ambient illuminance over an exponential range and characterize patterns of shifting from indoors to outdoors.[24,25]

Several reviews report that extensive use of digital devices, such as computers and cell phones, could be myopiogenic.[32–34] According to the questionnaire used here, estimates of electronic device use were approximately 12 hours per day; electronic devices included handheld devices, computers, and television. In our study, electronic device use was similar for myopic and nonmyopic children. Given an objectively measured sleep duration of approximately 8 hours, this finding suggests that children were on electronic devices for approximately 75% of their daily wake time. We speculate that similar to low time outdoors, the very high use of electronic devices was due to virtual schooling adopted during the COVID-19 pandemic, although there might be preexisting differences in use between nonmyopes and myopes that we did not test. The effects of extensive computer use with decreased outdoor time and lower level of physical activity may pose changes on long-term general health, in addition to potential changes in children's refractive status. Longitudinal studies investigating these behavioral factors will shed light on their role in myopia and in overall health.

Limitations of the current study include a relatively small sample size. We did not have prior estimates of objectively measured near work in a similarly aged cohort, and in that sense, this was an exploratory study. Based on the obtained between-group differences and pooled standard deviations, sample sizes were reassessed *post hoc* using G*Power (Heinrich Heine Universitat, Dusseldorf, Germany). If these values are true reflections of the population, sample sizes of 44 in each group are expected to provide a power of 0.80 and significance values of .05 for the duration of near viewing. In addition, self-reported refractive status was used to categorize children as myopic, which was necessary to limit visits to the laboratory and minimize contact to help reduce the spread of COVID-19. Although the indirect method of reporting refractive status used here has shown reasonable sensitivity and specificity, and study personnel were able to observe participants' habitual refractive correction, if any, when delivering study material, the exact refractive status could not be ascertained in all the children. Cycloplegic refraction is recommended in future studies. Half of the study population was Asian and had a higher prevalence of myopia than the White children in the study. Future studies including a wide range of ethnicities representative of demographic distribution will be valuable to understand the role of near work and outdoor time on myopia pathogenesis. The study design was cross-sectional; thus, inferences cannot be drawn about the causal relationship between increased electronic device use, near work, and decreased time outdoor on myopia onset or progression. Environmental and behavioral measures recorded for 1 week using the Actiwatch and Clouclip might not represent the full scope of visual behavior exhibited by children. Nonmyopic children had to wear plano spectacles to hold the Clouclip, which may have altered their behaviors. Findings were also limited by the use of subjective methods to quantify electronic device use.

In conclusion, the Clouclip and Actiwatch showed good utility in objective quantification of near and intermediate viewing, light exposure, and time outdoors, with the added advantage of quantifying temporal patterns in children's habitual environment. Differences were observed between refractive error groups, with myopic children demonstrating increased near and intermediate viewing and decreased light exposure. Further use of wearable sensors complemented with parent questionnaires will contribute to the understanding of behavioral factors in myopia pathogenesis.

ARTICLE INFORMATION

Supplemental Digital Content: Appendix 1: The University of Houston Near Work, Environment, Activity, and Refraction (UH NEAR) Survey, administered to parents of all participants in this study, is available at http://links.lww.com/OPX/A558. The UH NEAR Survey includes questions regarding demographics and ocular history and asks parents and their children to estimate the time per day spent in various activities, both on weekdays and on weekend days.

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REFERENCES

1. Holden BA, Fricke TR, Wilson DA, et al. Global Prevalence of Myopia and High Myopia and Temporal Trends from 2000 through 2050. Ophthalmology 2016;123:1036–42.

2. Flitcroft DI. The Complex Interactions of Retinal, Optical and Environmental Factors in Myopia Aetiology. Prog Retin Eye Res 2012;31:622–60.

3. Fricke TR, Holden BA, Wilson DA, et al. Global Cost of Correcting Vision Impairment from Uncorrected Refractive Error. Bull World Health Organ 2012;90:728–38.

4. Rose K, Harper R, Tromans C, et al. Quality of Life in Myopia. Br J Ophthalmol 2000;84:1031–4.

5. Mutti DO. Hereditary and Environmental Contributions to Emmetropization and Myopia. Optom Vis Sci 2010;87:255–9.

6. Chakraborty R, Ostrin LA, Nickla DL, et al. Circadian Rhythms, Refractive Development, and Myopia. Ophthalmic Physiol Opt 2018;38:217–45.

7. Saw SM, Shankar A, Tan SB, et al. A Cohort Study of Incident Myopia in Singaporean Children. Invest Ophthalmol Vis Sci 2006;47:1839–44.

8. Li SM, Li SY, Kang MT, et al. Near Work Related Parameters and Myopia in Chinese Children: The Anyang Childhood Eye Study. PLoS One 2015;10:e0134514.

9. Lin Z, Vasudevan B, Jhanji V, et al. Near Work, Outdoor Activity, and Their Association with Refractive Error. Optom Vis Sci 2014;91:376–82.

10. Mutti DO, Mitchell GL, Moeschberger ML, et al. Parental Myopia, Near Work, School Achievement, and Children's Refractive Error. Invest Ophthalmol Vis Sci 2002;43:3633–40.

11. You X, Wang L, Tan H, et al. Near Work Related Behaviors Associated with Myopic Shifts among Primary School Students in the Jiading District of Shanghai: A School-based One-year Cohort Study. PLoS One 2016;11:e0154671.

12. Jones LA, Sinnott LT, Mutti DO, et al. Parental History of Myopia, Sports and Outdoor Activities, and Future Myopia. Invest Ophthalmol Vis Sci 2007;48:3524–32.

13. Rose KA, Morgan IG, Ip J, et al. Outdoor Activity Reduces the Prevalence of Myopia in Children. Ophthalmology 2008;115:1279–85.

14. Ho CL, Wu WF, Liou YM. Dose-response Relationship of Outdoor Exposure and Myopia Indicators: A Systematic Review and Meta-analysis of Various Research Methods. Int J Environ Res Public Health 2019;16:2595.

15. He M, Xiang F, Zeng Y, et al. Effect of Time Spent Outdoors at School on the Development of Myopia among Children in China: A Randomized Clinical Trial. JAMA 2015;314:1142–8.

16. Lingham G, Yazar S, Lucas RM, et al. Time Spent Outdoors in Childhood Is Associated with Reduced Risk of Myopia as an Adult. Sci Rep 2021;11:6337.

17. Xiong S, Sankaridurg P, Naduvilath T, et al. Time Spent in Outdoor Activities in Relation to Myopia Prevention and Control: A Meta-analysis and Systematic Review. Acta Ophthalmol 2017;95:551–66.

18. Cao K, Wan Y, Yusufu M, et al. Significance of Outdoor Time for Myopia Prevention: A Systematic Review and Meta-analysis Based on Randomized Controlled Trials. Ophthalmic Res 2020;63:97–105.

19. 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;119:2141–51.

20. Whiteman D, Green A. Wherein Lies the Truth? Assessment of Agreement between Parent Proxy and Child Respondents. Int J Epidemiol 1997;26:855–9.

21. Najman JM, Williams GM, Nikles J, et al. Bias Influencing Maternal Reports of Child Behaviour and Emotional State. Soc Psychiatry Psychiatr Epidemiol 2001;36:186–94.

22. Rah MJ, Mitchell GL, Mutti DO, et al. Levels of Agreement between Parents' and Children's Reports of Near Work. Ophthalmic Epidemiol 2002;9:191–203.

23. Ostrin LA. Objectively Measured Light Exposure in Emmetropic and Myopic Adults. Optom Vis Sci 2017; 94:229–38.

24. Alvarez AA, Wildsoet CF. Quantifying Light Exposure Patterns in Young Adult Students. J Mod Opt 2013;60:1200–8.

25. Dharani R, Lee CF, Theng ZX, et al. Comparison of Measurements of Time Outdoors and Light Levels as Risk Factors for Myopia in Young Singapore Children. Eye 2012;26:911–8.

26. Williams R, Bakshi S, Ostrin EJ, et al. Continuous Objective Assessment of Near Work. Sci Rep 2019;9:6901.

27. Read SA, Collins MJ, Vincent SJ. Light Exposure and Physical Activity in Myopic and Emmetropic Children. Optom Vis Sci 2014;91:330–41.

28. Ostrin LA, Sajjadi A, Benoit JS. Objectively Measured Light Exposure during School and Summer in Children. Optom Vis Sci 2018;95:332–42.

29. Read SA, Collins MJ, Vincent SJ. Light Exposure and Eye Growth in Childhood. Invest Ophthalmol Vis Sci 2015;56:6779–87.

30. Ostrin LA, Read SA, Vincent SJ, et al. Sleep in Myopic and Non-myopic Children. Transl Vis Sci Technol 2020;9:22.

31. Bhandari KR, Ostrin LA. Validation of the Clouclip and Utility in Measuring Viewing Distance in Adults. Ophthalmic Physiol Opt 2020;40:801–14.

32. Lanca C, Saw SM. The Association between Digital Screen Time and Myopia: A Systematic Review. Ophthalmic Physiol Opt 2020;40:216–29.

33. Liu S, Ye S, Xi W, et al. Electronic Devices and Myopic Refraction among Children Aged 6–14 Years in Urban Areas of Tianjin, China. Ophthalmic Physiol Opt 2019;39:282–93.

34. Wong CW, Tsai A, Jonas JB, et al. Digital Screen Time during the COVID-19 Pandemic: Risk for a Further Myopia Boom?Am J Ophthalmol 2021;223:333–7.

35. Ojaimi E, Rose KA, Smith W, et al. Methods for a Population-based Study of Myopia and Other Eye Conditions in School Children: The Sydney Myopia Study. Ophthalmic Epidemiol 2005;12:59–69.

36. Walline JJ, Zadnik K, Mutti DO. Validity of Surveys Reporting Myopia, Astigmatism, and Presbyopia. Optom Vis Sci 1996;73:376–81.

37. Wen L, Cao Y, Cheng Q, et al. Objectively Measured Near Work, Outdoor Exposure and Myopia in Children. Br J Ophthalmol 2020;104:1542–7.

38. Wen L, Cheng Q, Cao Y, et al. The Clouclip, a Wearable Device for Measuring Near-work and Outdoor Time: Validation and Comparison of Objective Measures with Questionnaire Estimates. Acta Ophthalmol 2021;99(7):e1222–35.

39. Cao Y, Lan W, Wen L, et al. An Effectiveness Study of a Wearable Device (Clouclip) Intervention in Unhealthy Visual Behaviors among School-age Children: A Pilot Study. Medicine 2020;99:e17992.

40. Ip JM, Saw SM, Rose KA, et al. Role of Near Work in Myopia: Findings in a Sample of Australian School Children. Invest Ophthalmol Vis Sci 2008;49:2903–10.

41. Hsu CC, Huang N, Lin PY, et al. Risk Factors for Myopia Progression in Second-grade Primary School Children in Taipei: A Population-based Cohort Study. Br J Ophthalmol 2017;101:1611–7.

42. 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;49:3858–63.

43. 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.

44. 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;53:2856–65.

45. Li M, Lanca C, Tan CS, et al. Association of Time Outdoors and Patterns of Light Exposure with Myopia in Children [published online April 15, 2021]. Br J Ophthalmol. doi:10.1136/bjophthalmol-2021-318918.

46. Wu PC, Chen CT, Lin KK, et al. Myopia Prevention and Outdoor Light Intensity in a School-based Cluster Randomized Trial. Ophthalmology 2018;125:1239–50.

47. Okudaira N, Kripke DF, Webster JB. Naturalistic Studies of Human Light Exposure. Am J Physiol 1983; 245:R613–5.

48. Figueiro MG, Hamner R, Bierman A, et al. Comparisons of Three Practical Field Devices Used to Measure Personal Light Exposures and Activity Levels. Light Res Technol 2013;45:421–34.

49. Saw SM, Chua WH, Hong CY, et al. Nearwork in Early-onset Myopia. Invest Ophthalmol Vis Sci 2002; 43:332–9.

50. Narayanasamy S, Vincent SJ, Sampson GP, et al. Visual Demands in Modern Australian Primary School Classrooms. Clin Exp Optom 2016;99:233–40.

51. Norton TT, Siegwart JT, Jr., Amedo AO. Effectiveness of Hyperopic Defocus, Minimal Defocus, or Myopic Defocus in Competition with a Myopiagenic Stimulus in Tree Shrew Eyes. Invest Ophthalmol Vis Sci 2006;47: 4687–99.

52. Napper GA, Brennan NA, Barrington M, et al. The Effect of an Interrupted Daily Period of Normal Visual Stimulation on Form Deprivation Myopia in Chicks. Vision Res 1997;37:1557–64.