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Light exposure profiles differ between myopes and non-myopes outside school hours

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ABSTRACT

Purpose Considering the putative role of light in myopia, and variations in socioeconomic, lifestyle, educational and environmental factors across ethnicities, we objectively investigated light exposure patterns in Indian school children.

Methods The light exposure profile of 143 school children (9–15 years, 50 myopes) recorded using a validated wearable light tracker for six continuous days was analysed. Additional data for non-school days were available for 87 children (26 myopes). The illuminance exposure levels, time spent outdoors and epoch (number of times participant is exposed to a predefined range of lux level per day) were compared between myopes and non-myopes across different light conditions: ≥1000, ≥3000, ≥5000 and ≥10 000 lux. For school days, light exposure profiles during (1) before school, school and after school hours; and (2) class, break and transition (when a student travels to and from school) time were analysed.

Results The overall median (IQR) daily illuminance exposure level, time spent outdoors and epochs at outdoors (≥1000 lux) were 807 (507–1079) lux/day, 46 (30–64) min/day and 9 (6–12) times/day, respectively. The daily illuminance exposure on non-school days was significantly higher in non-myopes than myopes (6369 (4508–9112) vs 5623 (2616–6929) lux/day, p=0.04). During transition time (school days), non-myopes had significantly higher illuminance exposure (910 (388–1479) vs 550 (263–1098) lux/day, p=0.04), spent more time outdoors (25 (10–43) vs 14 (4–29) min/day, p=0.01) and had higher outdoor epochs (6 (4–11) vs 5 (2–8) times/day, p=0.01) than myopes.

Conclusions A small but significant difference in illuminance exposure, time spent outdoors and epoch was noted between myopes and non-myopes during transition time, which may have implications in myopia control.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Objective measurement of light exposure profiles in Chinese and Caucasian children has shown that non-myopic children were exposed to brighter illuminance exposure levels and spend greater time outdoors compared with myopic children.

WHAT THIS STUDY ADDS

⇒ The behavioural pattern related to the light exposure profile of school-going children in India is explored further. Additionally, we found that on a typical school day, non-myopic children were exposed to brighter illuminance levels, had greater time spent outdoors and had a higher number of outdoor epochs (number of times participant is exposed to ≥1000 lux per day) during the transition time (1 hour before and after school hours), than myopes.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ These findings show an association with light exposure and refractive error, but not necessarily causation. There is some pattern observed during transition time, which can be investigated further to explore the causation relation between light exposure and myopia development or progression in children.

INTRODUCTION

Outdoor light exposure in early childhood is reported to prevent or delay the onset of juvenile myopia.[1–4] A recently published overview of systematic reviews showed early exposure to bright outdoor light reduced the relative risk of myopia incidence by 24–46% in different ethnicities.[2] Several factors have been proposed to explain the protective mechanisms of outdoor light exposure,[5 6] namely, differences in illuminance level[7–10] and spectral composition[11–13] between outdoor natural and indoor artificial light, uniform dioptric field causing relaxed accommodative posture[14] and release of hormones such as dopamine[15–17] and melatonin[18–20] that regulate homoeostatic ocular growth.

Intervention studies conducted in school children allowing additional time outdoors as an intervention showed a relative risk reduction of incidence myopia.[1 8] Furthermore, cross-sectional studies have explored the light exposure pattern in different populations with and without myopia.[21 22] Until recently, information collected relating to light exposure patterns in children was based on self-reporting. However, the development of wearable light trackers has allowed researchers to obtain such information objectively.[23] Read *et al*[22] used wearable light trackers and reported significantly longer duration of outdoor light exposure among Australian children (105±42 min/day) compared with Singaporean children (61±40 min/day, p=0.005). Although some studies have suggested an association between light exposure patterns and refractive status,[24 25] other studies have found no such association. For example, Read *et al* reported significantly lower illuminance exposure levels (915±519 vs 1272±625 lux) and less time spent outdoors (91±44 vs 127±51 min/day) in a myopic cohort compared with their non-myopic Australian peers.[24] On the contrary, Chinese myopic and non-myopic children showed similar illuminance exposure levels (739±429 vs 832±440 lux, respectively) and time spent outdoors (44±25 vs 51±21 min/day).[25] Likewise, Ostrin[26] used the Actiwatch Spectrum and found no significant differences in light exposure levels and time spent outdoors between myopes (1611±1055 lux, hours:min 2:05±1:06 hours/day) and emmetropes (1758±1385 lux, 1:46±0:51 hours/day) in the adult population (21–65 years).

Although myopia is considered to be pandemic, geographical and cultural diversities such as socioeconomic status, lifestyle, education and environmental variations have directly or indirectly caused a heterogenous distribution of myopia prevalence across the globe.[27] Recent studies from India reported a gradual increase in myopia prevalence, which is predicted to reach around 48% by the year 2050 in urban school children,[28] and 18% are considered to have rapid myopia progression.[29] Various India-centric public health strategies described the role of exposure to bright ambient light levels to counteract the rising prevalence of myopia and its complications in India.[30] Most published studies exploring the light exposure pattern in myopes and non-myopes, and the association between outdoor light and myopia are either from Caucasian or East Asian populations. However, objective quantification of light exposure patterns in school children in India is yet to be explored. The present study used a personalised wearable light tracker to objectively explore the light exposure patterns in myopic and non-myopic school children. In addition, we also investigated if the light exposure pattern in myopes and non-myopes differs during school hours, breaks and non-school hours.

METHODS

This study was conducted as part of a one year longitudinal study, 'Light Outdoor Myopia Study' (LOMS), in two schools of Hyderabad in India, which were similar to each other with respect to the structure of the school day. The students studying in both schools had similarities in terms of age group, socioeconomic status and culture. This study reported the baseline findings of LOMS, and data collection was conducted in the months of November and December 2021. The procedures conformed to the tenets of the Declaration of Helsinki. All the study protocols were explained in detail to the school principal and students in English and native language before obtaining written consent from the school principal and parents of each participant (student). There was no involvement of participants or the public in designing, conducting, reporting, or dissemination plans of this research study.

Participants visual acuity, refractive error and axial length measurement

A total of 202 schoolchildren aged 9–15 years were included in the study. Unaided monocular distance visual acuity was measured using a LogMAR visual acuity chart calibrated for a 4-metre distance. Refractive error was determined in a non-cycloplegic state using an open-field auto-refractor (Shin Nippon, NVision-K 5001, Japan) with a target placed at 4 metres to ensure a relaxed accommodative state of the participants. Axial length was measured using a Lenstar LS 900 optical non-contact biometer (Haag Streit, Switzerland). An average of five readings were obtained to determine final refractive error, and an average of three readings to determine the axial length. All the measurements were taken at room illuminance ranging between 255 and 500 lux.

After the screening, participants were categorised into myopic and non-myopic groups based on visual acuity and spherical equivalent refraction (SER—defined as sum of sphere and half of cylinder). Participants qualified for the myopic group if their unaided visual acuity was worse than equal to 0.1 LogMAR and SER of ≤−0.75 D with the sphere being ≤−0.50 D, in either or both of the eyes. Both the criteria of visual acuity and SER were needed to be achieved to ensure the participants categorised as myopic were true myopes, where −0.50 D would result in one line reduction in visual acuity. Participants who did not meet these criteria were classified as non-myopes.

Light tracker

All the participants belonging to both myopic and non-myopic groups were dispensed a validated personalised wearable 'MyLyt' tracker to capture information related to light exposure measured as a function of illuminance level (lux) in real-time. The details of MyLyt tracker related to technical specifications, validation and safety, and precaution measures have been described elsewhere.[31] The tracker was clipped onto the school uniform (during school time) or the casual wear (outside of school time) worn by the participant, below the neck at the level of the upper thoracic region. They were instructed to immediately relocate the trackers onto new clothes after changing the school uniform. The MyLyt tracker has the capacity to record data continuously for a maximum of 7 days at a sampling rate of 1 data/min when fully charged. To minimise loss of data collection, a criterion of six consecutive days was used. Trackers were dispensed strategically such that the given time frame constituted at least one non-school day. Each participant was given verbal and written instructions about the safety and appropriate handling measures of the tracker. The trackers were fully charged before being dispensed to participants to avoid the risk of inadequate data recording within the given time frame. Teachers were asked to monitor the mounting position of trackers to improve the accuracy of data recording. Illuminance exposure level, time spent in different light levels, and epoch were quantified based on the data obtained from the tracker.

Illuminance level, time spent and epoch analyses

The 'illuminance exposure level' recorded in real-time were further categorised into ≥1000, ≥3000, ≥5000 and ≥10 000 lux to understand the differences in light exposure patterns in a variety of outdoor light conditions between myopic and non-myopic children. Here 'outdoor' refers to a location or condition where light levels are ≥1000 lux, while 'indoor' is a location or condition where light levels are <1000 lux.[24–26] 'Time spent' is defined as the total time spent in a given range of light intensity and is calculated by adding up a total number of minutes spent within the defined range. 'Epoch' is defined as the frequency that the participant is exposed to a certain predefined range of lux levels. Both, time spent and epoch were analysed for the same category of outdoor photopic light levels as was for illuminance exposure levels (≥1000, ≥3000, ≥5000 and ≥10 000 lux).

School days analysis

Although data were recorded over 24 hours/day, for the purpose of statistical analysis, data obtained between 7:30 to 18:00 clock hours were used. This was based on the average time of sunrise and sunset in India (https://www.timeanddate.com/sun/india/hyderabad) and the time range between which 70% of the participants showed some activity. The light captured by MyLyt was used as a proxy for participants' activity, that is, the corresponding time recording first '0' lux after 17:30 clock hours, and continuing as '0' lux for a minimum 1 hour was considered as the stopping criterion for participants' activity for the day. Likewise, the corresponding time recording first ≥1 lux after 5:30 clock hours in the morning, and continues without recording '0' lux for the next consecutive 60 min marks the starting point for the participant's activity for the day. Additionally, between 7:30 and 18:00 clock hours, if a light tracker logged identical illuminance values consecutively for more than 10 min, such data were considered invalid and were excluded from further analysis. This was done to avoid the inclusion of erroneous light data in the final analyses, as the tracker records identical values only when the participant removes the tracker from its designated mounting location and leaves it somewhere behind a fixed place without moving.

Considering children spend most of their time at school, the primary analyses were conducted using data from school day to explore the impact of school hours on the light exposure pattern of children. School days were further categorised into three groups: before school (7:30–9:00 clock hours), school (9:01–15:15) and after school hours (15:16–18:00) (figure 1). Additional analyses were conducted to understand if there are any differences in light exposure patterns during class time, break

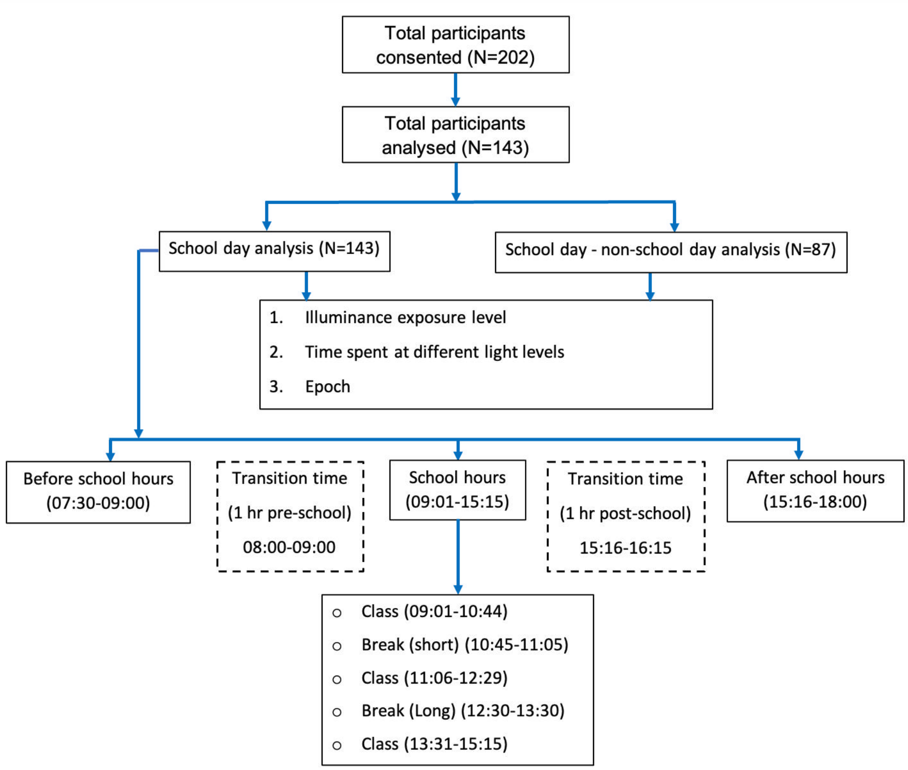

Figure 1 Flowchart depicting analyses protocol of the study.

time and transition time. ‘Class time’ is defined as the time when students are inside the classroom conducting an academic activity. ‘Break time’ is comprised of a break from continuous classes and typically occurs twice during school hours, when students are free to be inside or outside the classroom. ‘Transition time’ is defined as the time when students are travelling to and from school which was 1 hour pre and 1 hour post school hours. The data set from each individual participant was considered valid if data from at least three school days were available for analysis.

School day and non-school day analysis

To understand the difference in the light exposure pattern between school and non-school days, a subset analysis was conducted where illuminance exposure level, time spent and epoch were analysed and compared between myopes and non-myopes. Data set from individual participants were considered valid if data from a minimum of three school days and one non-school day were available for analysis. In India, a typical week consists of six school days and one non-school day.

Statistical analysis

Of the 202 participants, 143 participants data were included for analyses. Data logged by MyLyt tracker were transferred to Microsoft Excel 2021 (Microsoft Corporation, USA) for data cleaning and processing. All the statistical analyses were performed using IBM SPSS Statistics 26 (IBM Corporation, USA). For each participant, the average value of the illuminance data from the available days (the mean of each day value) were calculated to determine the illuminance exposure level, time spent and epochs under different light levels. Cumulative illuminance exposure level over a day was calculated from the averaged illuminance exposure level for available days.

For all three parameters, that is, illuminance exposure level, time spent under different light levels, and epoch, non-parametric tests were used, as indicated by the normality test (Shapiro-Wilk test). On a typical school day, these three light exposure parameters were compared during (1) before school, school and after school hours, and (2) class time, break time and transition time using Friedman tests along with Bonferroni correction to reduce the risk of a type I error. A Wilcoxon signed-rank test was used to compare paired data between school days and non-school days. Likewise, Mann-Whitney U tests were used to test the significance of the difference obtained between two independent variables, including refractive groups (non-myopes vs myopes), and gender (male vs female). The statistical analyses between included and excluded participants were conducted using the Mann-Whitney U test for age, SER and axial length distribution, and χ^2 test for gender and proportion of myopic participants. Data are represented as median (IQR: Q1–Q3) and a p value <0.05 was considered as statistically significant. A multivariate linear regression model was used to understand the association between various light exposure parameters (ie, average daily illuminance exposure level, outdoor illuminance exposure levels (≥1000 lux), time spent outdoors (≥1000 lux), epoch at outdoors (≥1000 lux) and cumulative illuminance exposure level) with SER and axial length as outcome variables, and adjusted for age and gender.

G*power (V.3.1.2.9, Heinrich Heine University) software was used for the sample size calculation. Considering myopia prevalence to be 30% in schools of Hyderabad,[32] 0.62 effect size (calculated from previous published studies[24 33] by using mean difference and SD for difference in illuminance exposure level (δ=0.62), and time spent outdoors (δ=0.75) between myopes and non-myopes), 0.05 significance level and 80% power, the sample size required was 118 (myopes (N)- 27, non-myopes (N)- 91).

RESULTS

Of the 202 participants who consented to take part in the study and were issued with trackers, data from 143 participants were included for school-day analysis, and a subset of 87 participants’ data was included for school-day and non-school-day analysis. The major reasons for excluding data of 59 participants for school day analyses were: lost tracker, missing data due to erroneous data recording, missing clinical ocular data and lacking a minimum of three school days data which could occur if the tracker was removed during the study period. The average number of school days during which light data was monitored in the participants was 5±1 days.

Comparative analysis between included (N=143) and excluded (N=59) participants is shown in online supplemental table S1. No significant difference in the proportion of myopic populations, and distribution of gender, SER and axial length was observed between included and excluded participants; however, excluded participants were slightly older than included ones (p<0.01). The demographic details of all the included participants, including myopic, and non-myopic groups are presented in table 1. Both the myopic and non-myopic groups had a similar age distribution (p=0.06).

School day analyses (N=143)

Illuminance exposure level

Overall, the median illuminance exposure level of 143 individuals was 448 (IQR 259–712) lux/day on school days, with no significant difference between myopes (382 (IQR 247–594) lux/day) and non-myopes (491 (IQR 289–735) lux/day, p=0.10). As shown in table 2, no significant difference in illuminance exposure level was observed between myopes and non-myopes under all the categories of outdoor photopic light condition. On a typical school day between 7:30 and 18:00 clock hours, school children demonstrated specific patterns of light exposure where four localised time zones had greater illuminance exposure levels, corresponding to either transition or break time (highlighted through light blue

Table 1 Demographic details of participants included in the final analysis of the study

Refractive group	Participants (N)	Age	Male (N)	SER (D)	AL (mm)
School day analysis					
All participants	143	12.4±1.4	67	−0.82±1.43	23.14±0.89
Myopes	50	12.7±1.5	30	−2.07±1.80	23.65±1.00
Non-myopes	93	12.2±1.4	37	+0.13±0.33	22.85±0.67
School day-non-school day analysis					
All participants	87	12.2±1.3	38	−0.75±1.33	23.07±0.91
Myopes	26	12.6±1.5	16	−2.10±1.75	23.76±0.99
Non-myopes	61	12.0±1.2	22	−0.14±0.34	22.77±0.68

Data is represented as mean±SD.
AL, axial length; SER, spherical equivalent refraction.

shades in figure 2A). Cumulative averaged illuminance exposure level for a day on a typical school day was found to be similar between myopes (216 680 (IQR 123 973–348 032) lux/day) and non-myopes (267 580 (IQR 141 709–447 226) lux/day, p=0.19).

Time spent outdoors, and epoch in different outdoor light conditions

Table 2 shows the time spent and epochs in all, myopic and non-myopic participants under different outdoor photopic light levels. School children in India spent 59 (IQR 32–86) min/day in typical outdoor photopic light level (≥1000 lux) on school days, which was similar between myopes and non-myopes (51 (IQR 26–82) vs 60 (IQR 34–90) min/day, respectively, p=0.16). Likewise, the median (IQR) number of times school children had typical outdoor light exposure was 21 (IQR 12–32) times/day on school days, with a non-statistically significant difference between myopes and non-myopes (19 (IQR 12–27) vs 24 (IQR 12–36) times/day, respectively, p=0.07).

Light exposure pattern during school hours

The median daily illuminance exposure level, time spent indoors (<1000 lux) and outdoors and epochs in outdoor light conditions on a typical school day during before school, school and after school hours, and during class, break and transition time are represented in online

Table 2 Median daily illuminance exposure, time spent and epochs under different photopic light conditions

Categories of illuminance level (lux)	All participants (median (IQR))	Myopes (median (IQR))	Non-myopes (median (IQR))
Illuminance exposure level (lux/day)			
≥1000 (typically considered outdoors)	3007 (2421–3688)	2767 (2399–3571)	3073 (2489–3695)
≥3000	5679 (4945–6745)	5454 (4844–5994)	5969 (5024–7073)
≥5000	8517 (7674–10218)	8339 (7626–8776)	8628 (7792–10 774)
≥10 000	14 042 (12 275–15 622)	14 183 (13 033–15 725)	13 996 (12 228–15 556)
Time spent in different outdoor photopic light levels (min/day)			
≥1000	59 (32–86)	51 (26–82)	60 (34–90)
≥3000	18 (8–33)	16 (6–27)	20 (8–34)
≥5000	7 (2–15)	6 (2–13)	7 (3–16)
≥10 000	2 (0–4)	1 (0–3)	2 (1–4)*
Epoch (times/day)			
≥1000	21 (12–32)	19 (12–27)	24 (12–36)
≥3000	11 (5–17)	8 (5–12)	12 (5–18)
≥5000	5 (2–11)	4 (2–6)	6 (2–11)
≥10 000	1 (0–3)	1 (0–2)	2 (0–4)

*Represents statistical significance at the level of <0.05 between myopes and non-myopes.

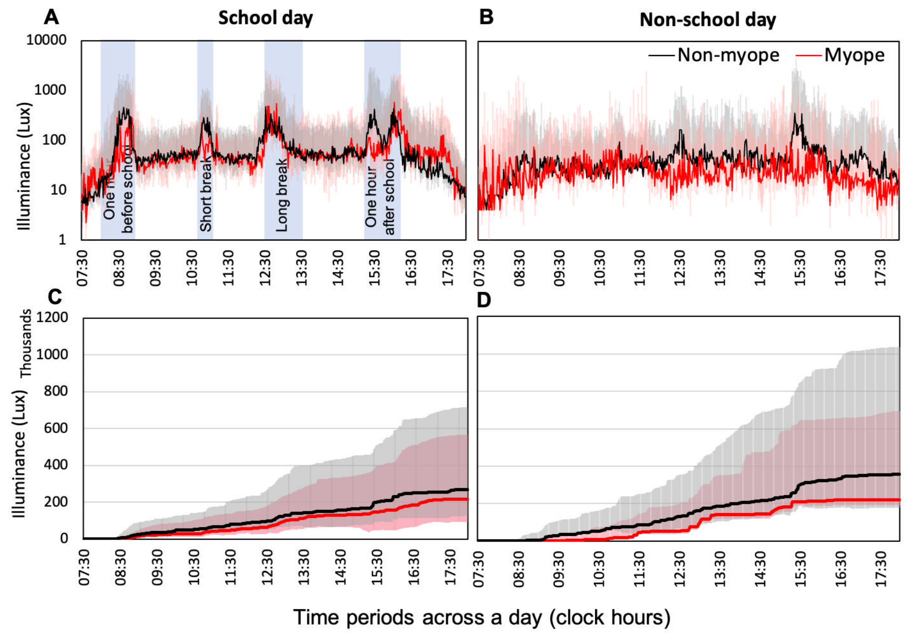

Figure 2 Distribution of daily median illuminance exposure level in myopic and non-myopic children between 7:30 and 18:00 clock hours on a school day (Panel A) and non-school day (Panel B). Four light blue-shaded regions in Panel A represent either transition time (1 hour before school and 1 hour after school) or break time (short break and long break) on a school day. Note: the logarithmic scale in the Y-axis for figures represented as panels A and B. Panel C and D represent cumulative illuminance exposure in myopes and non-myopes between 7:30 and 18:00 clock hours on a school day and non-school day, respectively. Solid black and red lines represent the median value for non-myopes and myopes, respectively, whereas shaded regions below and above the median line represent first and third quartiles, respectively.

supplemental figure S1. The median daily illuminance exposure level was similar between myopes and non-myopes during before school, school and after school hours (p≥0.07). While the differences in time spent outdoors during before school hours (non-myopes vs myopes: 6 (1–16) vs 3 (0–9) min/day, p=0.05), and epochs during after school hours (5 (3–10) vs 4 (1–7) times/day, p=0.02) were significantly different between non-myopes and myopes, the absolute difference was minimal.

Interestingly, during the transition time, non-myopes were found to have significantly higher median daily illuminance exposure levels (910 (388–1479) vs 550 (263–1098) lux/day, p=0.04), spend more time outdoors (25 (10–43) vs 14 (4–29) min/day, p=0.016), and have relatively higher epochs in outdoor photopic light conditions (6 (4–11) vs 5 (2–8) times/day, p=0.01), compared with myopes (online supplemental figure S1). Conversely, during the transition time, myopes were found to spend significant but minimally greater time indoors than non-myopes (78 (63–99) vs 73 (59–88) min/day, respectively, p=0.04). Both myopes and non-myopes had similar light exposure patterns during class and break time (p≥0.30).

Association between light exposure parameters with SER and axial length

The multivariate linear regression analyses reporting the association between various light exposure parameters with SER and axial length are shown in online supplemental table S2. None of the light exposure parameters, that is, average daily illuminance exposure level, outdoor illuminance exposure levels (≥1000 lux), time spent outdoors (≥1000 lux), epoch at outdoors (≥1000 lux) and daily cumulative illuminance exposure levels were associated with SER (p≥0.36) or axial length (p≥0.43).

School day - non-school day analysis (N=87)

Figure 2 illustrates the pattern of illuminance exposure level in myopic and non-myopic children between 7:30 and 18:00 clock hours on a school day (Panel A) and non-school day (Panel B). Unlike school days where the illuminance exposure pattern had four specific time zones representing higher exposure levels, the non-school day was devoid of this pattern (Panel 2B). The median cumulative illuminance exposure level was found to be similar between myopes and non-myopes on both school days (207 935 (IQR 108 670–287 993] vs 221 988 (IQR 134 494–353 311) lux, respectively, p=0.47) and a non-school day (221 515 (IQR 31 669–417 931) vs 316 939 (IQR 152 825–586 193) lux, p=0.07, figure 2).

Overall, based on the data from six full days (involving both school and non-school days), median (IQR) illuminance exposure level was 807 (IQR 507–1079) lux/day, which was significantly higher on a non-school day (791 (397–1603) lux/day) compared with a school day (672 (IQR 502–998) lux/day, p=0.002). Under typical outdoor light conditions of ≥1000 lux, non-myopes were exposed to significantly higher illuminance levels (6369 (IQR 4508–9112) lux) than myopes (5623 (IQR 2616–6929)

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lux, p=0.04), on a non-school day. The illuminance exposure level was similar in myopes and non-myopes across all other categories of outdoor light conditions (≥3000, ≥5000 and ≥10 000 lux) on both the school and non-school days.

The median time spent by children in outdoor light conditions (≥1000 lux) was 46 (IQR 30–64) min/day, and the values were not significantly different between myopes and non-myopes in any of the outdoor light conditions in both school (p=0.43) and non-school days (p=0.12). Likewise, the number of times school children were exposed to outdoor light conditions of ≥1000 lux was 9 (6–12) times/day. Epochs were similar between myopes and non-myopes over ≥1000, ≥3000 and ≥5000 lux (p≥0.09) on both school and non-school days. However, over ≥10 000 lux, non-myopes had significantly higher epochs than myopes on a non-school day (6 (IQR 1–14) vs 3 (1–7) times/day, respectively, p=0.04).

No significant difference in daily illuminance exposure level, cumulative illuminance exposure level, and illuminance exposure level, time spent and epochs in an outdoor light condition (≥1000 lux) were found based on differences in gender (p≥0.13).

DISCUSSION

The is the first study to objectively quantify the light exposure pattern of school children in India using a personalised wearable light tracker. Based on the data that includes both school and non-school days, we found that school children in India were exposed to daily illuminance exposure levels of 807 (IQR 507–1079) lux/day, spent 46 (IQR 30–64) min/day outdoors and had epochs of 9 (IQR 6–12) times/day in outdoor light conditions. Non-myopic children were exposed to significantly higher illuminance levels in outdoor light conditions of ≥1000 lux compared to their myopic peers on non-school days, whereas a small but non-significant difference was found between the two groups for other categories of light levels. Importantly, travelling to and from school (transition time) on a typical school day, non-myopes were exposed to significantly higher median daily illuminance exposure levels, spent more time outdoors and had a greater number of epochs in outdoor light conditions than myopes.

In the current study, trackers were used to objectively quantify light-related parameters in school children in India. Saxena *et al*[34 35] used questionnaires to explore time spent outdoors by children with myopia progression in northern India, and reported that children with myopia progression spent (mean±SD) 13.95±1.90 hours/week performing outdoor activities. The current study shows myopes spent 44±25 min/day (mean±SD) at outdoors (≥1000 lux). When extrapolated to a week's time period, the mean value reaches to 5.13 hours/week, which is substantially lesser than that reported by Saxena *et al*. However, questionnaires are subjective and have the disadvantage of recall bias over light trackers.[23] table 3 summarises the findings reported by several studies[24–26 33 36 37] that used wearable light trackers to objectively quantify light-related parameters among different refractive groups of different ethnicities. Since these studies reported their results as mean±SD, for the purpose of comparison, we have reported our results as both mean±SD and median (IQR) in the table. The mean illuminance exposure level among myopes and non-myopes in Indian children reported in the current study (myopes (mean±SD): 789±511 lux/day, non-myopes: 908±466 lux/day) is comparable with the results reported by Wen *et al*[25] in Chinese children (myopes: 739±429 lux/day, non-myopes: 832±440 lux/day). However, when compared with the Americans[26] (myopes: 1612±1055, non-myopes: 1759±1385 lux/day) and Australians[24] (myopes: 915±519 lux/day, non-myopes: 1272±625 lux/day), illuminance exposure levels were substantially lower in the current study. Indian children were also observed to spend less time outdoors compared with their Chinese, Singaporean and Australian peers. These could be due to variation in the types of trackers used and their mounting positions, discrepancies in the number of daily sports hours incorporated in the academic curriculum, number of non-school days per week, awareness of the importance of sunlight exposure among parents and children and difference in the number of daylight hours between India and other countries. We used MyLyt which is mounted just below the neck in the upper thoracic region, whereas, Wen *et al*[25] used a Clouclip mounted on the temple of the spectacle, Li *et al*[37] used FitSight, and Ostrin[26] and Read *et al*[24] used Actiwatch worn on the wrist. Schools in India typically function 6 days a week with one non-school day, and are likely to lack dedicated daily sports hours during the school time. Most other countries are likely to have five functional school days with two non-school days in a week including dedicated sports hours incorporated in the academic curriculum. Furthermore, the average daylength available for sunlight exposure in Hyderabad during data collection was (hh:mm) 11:13±00:12 (between November and December 2021, derived from https://www.timeanddate.com/sun/india/hyderabad), which was lower than the daylength in Australia (12:35±00:58, between July and December),[24] USA (12:10±01:19, representative data of 2021 across 12 months- derived from https://www.timeanddate.com/sun/usa/houston) and China (12:09±1:14, representative data of 2021 across 12 months- derived from https://www.timeanddate.com/sun/china/changsha). Differences in season when data collection was conducted might also result in differences in both light exposure duration/intensity as well as outdoor activity/behaviour compared with the other studies. Li *et al*[37] reported substantially lower average daily light exposure level in Singaporean children (average of all participants- 458±228 lux/day) compared with current and other studies (table 3). Differences in educational demands (homework load and afterschool enrichment classes), lifestyle and sociocultural factors were the plausible reasons reported in the study for observing such

Table 3 Results from previously published studies and comparison with current study with respect to light exposure parameters—average illuminance exposure, time spent outdoors and epoch at outdoors

Study	Participant (n) (Age in years)	Duration and sampling frequency per data	Device used (Duration when data was analysed)	Result		
				Average illuminance exposure (Lux)	Time outdoors (≥1000 lux) (min/day)	Epoch outdoors (≥1000 lux) (no. of peaks/day)
Dharani *et al*, Singapore[33]	M: 65, NM: 52 (6–12)	1 week (5 min)	HOBO pendant temp/light (7:00–19:00)	–	School day M: 62±46 NM: 65±64 Non-school day M: 83±58 NM: 89±68	–
Read *et al*, Australia[24]	M: 41, Emm: 61 (10–15)	2 weeks (30 s)	Actiwatch-2 (6:00–18:00)	M: 915±519 Emm: 1272±625	M: 91±44 Emm: 127±51	–
Ostrin, USA[26]	M: 37, Emm: 18 (21–65)	2 weeks (30 s)	Actiwatch Spectrum (24 hours)	M: 1612±1055 Emm: 1759±1385	M: 106±51 Emm: 125±66	–
Landis *et al*, Australia[36]	M: 40, NM: 40 (10–15)	2 weeks (30 s)	Actiwatch 2 (NR)	–	School day M: 81±5.4 NM: 111±6 Non-school day M: 76±9 NM: 116±12.6	–
Wen *et al*, China[25]	M: 28, NM: 58 (10.13±0.48)	1 week (2 min)	Clouclip (7:00–20:00)	M: 739±429 NM: 832±440	M: 100±42 NM: 119±56	M: 7.22±1.53 NM: 8.31±1.71
Li *et al*, Singapore[37]	M: 204, NM: 279 (9)	1 week (1 min)	FitSight (7:00–19:00)	458±228*	100±93*	1.7±1.0*
Current study 2023, India	M: 50, NM: 93 (9–15)	6 days (1 min)	MyLyt (7:30–18:00)	M: 789±511 NM: 908±466	M: 44±25 NM: 51±21	M: 9±5 NM: 10±6
			Median values	M: 649 (500–893) NM: 863 (557,1099)	M: 37 (24–58) NM: 46 (33–64)	M: 8 (5–13) NM: 9 (7–12)

*Represents the average data of all the participants (myopic and non-myopic participants). The last row represents the median values of the current study.
Emm, emmetropes; M, myopes; NM, non-myopes; NR, not reported.

lower average daily light exposure levels in Singaporean children.

We observed a typical temporal pattern of light exposure in school children on a school day, where multiple peaks of higher illuminance levels were present corresponding to either transition time or break time (figure 2A), juxtaposed to an asymmetrical pattern on a non-school day (figure 2B). Wen *et al*[25] reported specific light exposure pattern among myopes and non-myopes on school day where non-myopes were exposed to higher light levels than myopes between 10:10 and 10:30, 12:20 and 14:10 and 16:00 and 17:30 clock hours corresponding to break time for outdoor physical exercise during school time, self-study time while at school and transition time from school to home, respectively. In the current study, non-myopes were exposed to relatively higher lux levels and time outdoors during the transition (08:00–09:00 and 15:16–16:15 clock hours) and break time (10:45–11:05 and 12:30–13:30 clock hours) (online supplemental figure S1). Wen *et al*,[25] reported that non-myopes tend to go outdoors during break time or walk to school from home and vice versa during their transition time, whereas their myopic peers stayed back inside the classroom or used vehicles as their mode of transport to and from school resulting in decreased illuminance exposure in myopes. A similar trend is speculated in our study as well; however, data related to the mode of travel between home and school were not collected in this study, so we were unaware of whether the mode of travel (walking, cycling, car or bus) affected the light levels in these children.

Although the differences in overall median daily illuminance exposure level (p=0.09) and time spent outdoors (p=0.26) by myopic and non-myopic children were not significant, non-myopes were exposed to a relatively higher illuminance level for relatively longer periods of time than myopes in the current study, which corroborates with the findings reported by earlier studies in children[25] and adult populations.[26 38] Evidence suggests that outdoor light exposure has a protective effect in reducing the relative risk of incident myopia.[2] In addition, it may also have a counterbalance effect to excessive near work which has been shown to be an independent risk factor for myopia development and progression.[39] On non-school days, non-myopes were exposed to brighter outdoor light, spent more time outdoors, had a greater number of epochs above 1000 lux and had greater cumulative illuminance exposure. Although during school days the differences between myopes and non-myopes were minimal, cumulative differences over time could be more significant and could have a potential effect on preventing myopia onset, which needs further investigation. With regards to our findings based on epoch, non-myopes had relatively higher epochs in all four categories of outdoor light conditions (table 2), during transition time on school day, and over ≥10 000 lux on non-school day, than myopes. Animal experiments in chicks[40] and macaques[41] indicated the protective effect of intermittent bright light exposure over continuous light exposure. It could be possible that ocular growth in human eyes may undergo a similar phenomenon to that of animal models; however, further studies are required to investigate the effect of intermittent bright light exposure and ocular growth in human eyes.

There are several strengths of the current study. We have holistically analysed parameters such as illuminance exposure, time spent and epoch across several categories of outdoor photopic ambient light conditions. A validated wearable personalised light tracker was used in the current study to obtain light-related data, with the tracker mounted just below the neck in the upper thoracic region. This mounting location is likely to be more widely accepted and can be used irrespective of the child's refractive status. A spectacle-mounted tracker on the other hand would require emmetropes to wear spectacles to enable the tracker to be mounted. Wrist-mounted trackers have a high chance of erroneous or falsified data recording if sleeves or any other physical material obstructs the light sensor. Likewise, there are certain limitations of this study. The light-related parameters were captured objectively for 6 days. This might relatively be a short span of time to draw significant conclusions on the association between outdoor light exposure and myopia in children of Indian ethnicity. Findings from our 1 year longitudinal data will provide further insights into the association between outdoor light on myopia development and progression in this group. The age of participants included in the current study ranged between 9–15 years. It is possible that diversities in the light-environment behavioural profile between myopes and non-myopes exhibit at a much earlier age during the emmetropisation period (<6 years), and when students complete their primary level of education (usually >10 years) light exposure pattern may become similar due to changes in the academic curriculum. Future studies should consider including younger children to understand the association between outdoor light and myopia. The light exposure profiles of school children are not analysed beyond 18:00 clock hours in the current study. However, the differences in mesopic and scotopic light exposure patterns between myopes and non-myopes and its association with myopia as indicated by Landis *et al*[36] should be explored further. The upper threshold of MyLyt tracker is 88 000 lux. If illuminance levels are higher than the threshold value, the tracker would still record an illuminance value as 88 000 lux. This could impact the overall light exposure profile of a non-myopic participant more than their myopic peers, considering that non-myopes are likely to be exposed to brighter outdoor light for longer duration than myopes. The lack of cycloplegic refraction in determining the refractive status of school children can overestimate myopes. However, the use of an open-field autorefractor with a fixating target placed at 4 metres minimised the effect of accommodation. While we used a cut-off of ≥1000 lux to indicate outdoors, it is worth highlighting that the illuminance cut-off not necessarily always mean/represent the outdoor location as indicated by Howell *et al*[42] and Bhandary *et al*.[9] In addition, it is possible that the participants were in indoor locations that had illuminance levels ≥1000 lux. Lastly, although the post-hoc Bonferroni test was considered to control for type I errors, as the number of multiple comparisons was higher, the likelihood of type I error cannot be fully eliminated.

In conclusion, this study objectively quantified the light exposure profile of school children in India in terms of illuminance exposure levels, time spent outdoors, and epoch. The light exposure profile is similar between myopes and non-myopes during the daytime on a typical weekday except in the transition (likely while travelling to and from school to home or vice versa) time. The role of intermittent bright light exposure on myopia development and/or progression needs to be further explored which may hopefully provide new insights in developing policy for myopia control.

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