Title: Influence of location, season and time of day in altering spectral composition of ambient light: Investigation for application in myopia

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Running title: Spectral composition of an ambient light

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Abstract

Purpose

Given that differences in the spectral composition of light between indoor and outdoor environments may contribute to the higher prevalence of myopia in children, this study aimed to investigate the variation in spectral composition of ambient light in different a) outdoor/indoor locations, b) time of a day, and c) seasons.

Methods

The spectral power distribution (SPD), categorised into short (380-500 nm), middle (505-565 nm) and long wavelengths (625-780 nm), was recorded using a hand-held spectrometer at three outdoor locations ('open playground', 'under shade of tree', and 'canopy') and three indoor locations ('room with multiple windows', 'closed room', and 'closed corridor)'. Readings were taken at five different time points (3-hours intervals between 6:30 and 18:00 clock-hours) on two days each during the summer and monsoon seasons.

Results

The overall median SPD (IQR [25^{th}-75^{th} percentile] W/nm/m^2) across three outdoor locations (0.11 [0.09,0.12]) was 157 times higher than indoor locations (0.0007 [0.0001,0.001]). A considerable locational, diurnal and seasonal variation was observed in the distribution of median SPD value, with a highest value recorded in the 'open playground' (0.27 [0.21,0.28]) followed by 'under shade of tree' (0.083[0.074,0.09]), 'canopy' (0.014[0.012,0.015]), and 'room with multiple windows' (0.023[0.015,0.028]). The relative percentage composition of short, middle and long wavelengths was similar in both the outdoor and indoor locations, with the proportion of middle wavelength significantly higher ($P<0.01$) than short and long wavelengths in all the locations except canopy.

Conclusion

Irrespective of variation in SPD values with location, time, day, and season, outdoor locations always exhibited significantly higher spectral power than indoor locations. The relative percentage composition of short, middle and long wavelengths of light are similar across all the locations. The findings establish a foundation for future research to understand the relationship of spectral power and the development of myopia.

Keypoints

1. Both the outdoor and indoor locations have similar relative percentage spectral composition of short, middle and long wavelengths of light.
2. While spectral composition remains similar, the spectral power of ambient light is higher (>100 times) in outdoor locations than indoors
3. If spectral composition of ambient light has any role to influence refractive status, then careful recommendations related to myopia management need to be accordingly developed.

Introduction

Exposure to bright outdoor light is known to protect against development of juvenile myopia.[1-7] The dose-response relationship between time spent outdoors and myopia indicates that 2 hours of daily outdoor light exposure is needed to reduce the incidence of myopia by 50%,[5] whereas the impact of time spent outdoors in relation to myopia progression is equivocal.[8] Several hypotheses have been proposed to explain the protective mechanism of outdoor light exposure against myopia, including release of dopamine from retina to inhibit the eye growth,[9, 10] constriction of pupil causing increased depth of focus and reduced retinal blur,[11, 12] and differences in the spectral composition and light intensity of indoor and outdoor light.[13-17]

Various animal studies have demonstrated that exposure to different monochromatic wavelengths of light have potential to influence the ocular growth.[15-22] In humans, a reduced myopic shift was observed in children who were wearing violet light transmitting contact lenses compared to those wearing partially violet light blocking contact lenses, over a period of 1 year.[17] Likewise, short term exposure (1 hour) to blue light in young adults either led to minimal changes in axial length (AL) or showed an inhibitory effect compared to red, green, dark and white light.[23, 24] In contrast, Jiang et al. recently reported reduction in myopia progression by 69.4% in children aged 8-13 years when exposed to repeated low-level red light therapy over a period of one-year in a multicentre randomized controlled trial.[25] These experiments were conducted in a well-controlled laboratory setting; however, in a real world environment, children are exposed to highly fluctuating natural outdoor light (sunlight) or several types of artificial indoor light where the illuminance levels are known to vary significantly with location types and time of the day.[26]

Spitschan et al.[27] investigated the spectral composition of ambient light in USA reporting significant variations in the spectral power between rural and urban areas, attributing to the possible light pollution by artificial sources of light in the urban areas. Variation of solar spectrum in different seasons was investigated as a function of 'average photon energy' (defined as a ratio of total irradiance contained in the spectrum to total photon flux density) by Bangar et al.[28], and reported average photon energy ranged between 1.70 to 2.01 eV across the year, with monsoon season having the highest average photon energy (1.90 to 1.98 eV).

The pattern of ambient red, green and blue (RGB) spectrum exposure in humans was investigated by two studies.[29, 30] Thorne et al.[29] reported daily and seasonal variation in the relative contribution (%) of red, green and blue spectrum exposure in young adults living in England. Significant difference in the relative exposure of blue light spectrum was observed between the seasons, especially in the evening, with a significantly higher contribution in the summer's evening compared to winter's evening. Likewise, using a cross-sectional study design, Ostrin[30] recorded the exposure of RGB spectrum in emmetropes and myopes, and reported no difference in the irradiance level between the two cohorts. Both studies used a wearable light tracker (Actiwatch-RBG monitors and Actiwatch-L monitors, Philips, USA) to record exposure to various light spectra and had no control over the movement and/or location of the participants. The latter is important as the distribution of spectral composition of ambient light in various outdoor and indoor locations where children spend most of their time is unknown.

Given that exposure to specific monochromatic wavelengths of light is known to influence ocular growth in animal models, and few recent short-term and randomized controlled trials also indicated similar effect on human eyes, it would be worth to investigate the composition of visible electromagnetic spectrum of light, specifically the distribution and power of short, middle and long wavelengths in various outdoor and indoor locations. This would be helpful while recommending outdoor light exposure as an anti-myopia strategy to children and parents. This study thus aimed to investigate the spectral composition of the visible electromagnetic spectrum of light in a) different outdoor and indoor locations, b) at different time point of the day, and c) in different seasons.

Methods

This was a prospective study conducted at L V Prasad Eye Institute, Hyderabad, India, located at a latitude of 17° 22' 31" N and longitude of 78° 28' 27" E. Since human participants were not involved in the study, ethics committee approval was not sought before starting the study. The electromagnetic spectrum ranging between 380 to 780 nm was captured using a Photonfy handheld spectrometer (SP-01-BLU, https://ledmotive.com/photonfy/) mounted on a tripod with the spectrometer lying at the plane of the examiners eye (5.6 ft or 142 cm above ground level). The device is factory-calibrated; however, every day prior capturing data, spectrometer was dark-calibrated following the instructions provided in the user manual (https://ledmotive.com/photonfy/) and an Android based Photonfy application. In short, the shutter in the device was positioned to fully cover the sensor, such that the sensor remained in blackout position. The measurement was then obtained and set as background. Following this, all other measurements were obtained for the day. The spectral resolution of the device is 12 nm with a wavelength accuracy of ±1 nm. All the recordings were captured by the same examiner keeping the integration time in automatic mode (range 5-5000 milliseconds). The spectrometer generates multiple reports related to colour; however, for the purpose of this study, data related to colour properties i.e., CIE 1931 (X,Y,Z) colour space, dominant wavelength and spectral power distribution (SPD- defined as a power of optical radiation emitted by an illuminant/light-source per unit area per unit wavelength) were extracted and analysed. The device gives absolute SPD values (raw data) at different wavelengths ranging between 380 to 780 nm at an interval of 5 nm.

Locations where measurements were recorded

The spectral composition was recorded in three outdoor locations, namely ‘open playground’, ‘under shade of tree’ and ‘canopy’, and three indoor locations, namely ‘room with multiple windows’, ‘closed room’ and ‘closed corridor’ located in and around the institute premise. The characteristics of these locations are detailed elsewhere[26] except 'closed room' and 'closed corridor'. The 'closed room' measured 3 x 2.88 x 3.2 m (length x width x height) with a single door, no windows and an LED light source. The 'closed corridor' measured 17.6 x 2 x 2.9 m with a LED light source. Figure 1 shows the pictorial representation of these locations.

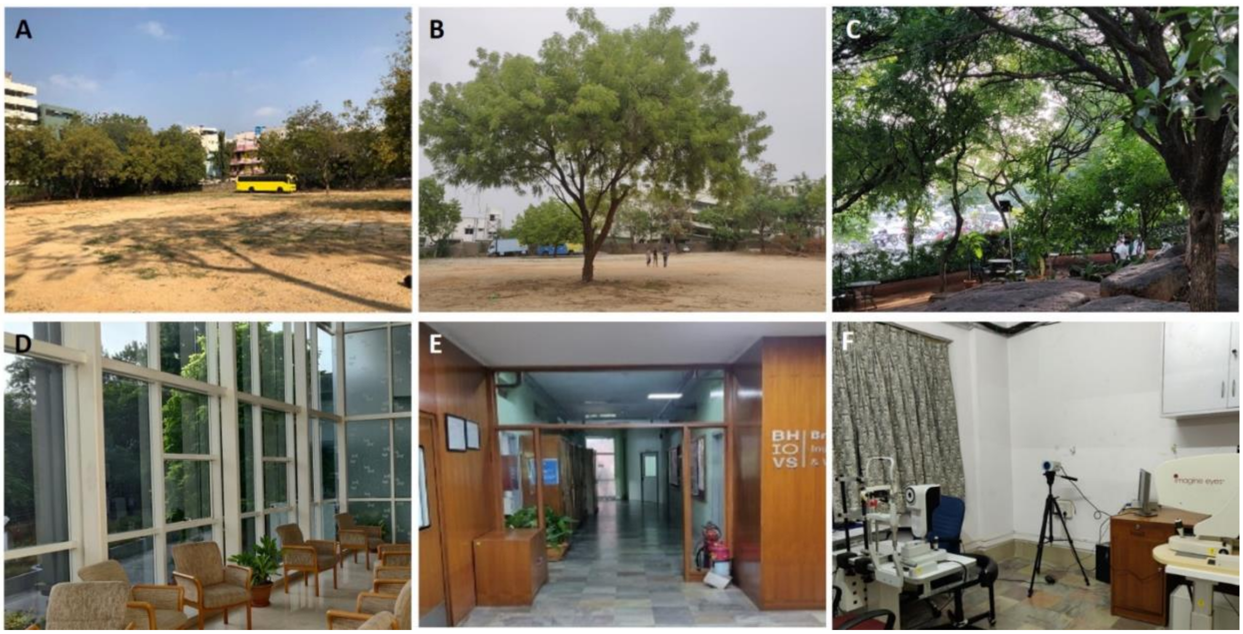

Figure 1. Outdoor (panel A-C) and indoor (panel D-F) locations. A- Open playground, B- Under shade of tree, C- Canopy, D- Room with multiple windows, E- Closed corridor, and F- Closed room.

Time of a day when measurements were recorded

Measurements in all the six locations were recorded five times across a day (6:30-7:00, 9:00-9:30, 12:30-13:00, 15:00-15:30, and 17:30-18:00 clock hours) within a 30-minute window period for each time point across all locations. The position and height of the tripod were fixed for each location throughout the measurement period. To observe the temporal change in spectral composition with days and seasons, measurements were recorded on four separate days, two days in each of the two different seasons. These included i) summer- March 2021 (March-June) with clear sky and arid environment, and ii) monsoon- July 2021 (July-October) with cloud cover and high humidity. The monsoon season was selected instead of winter because of the significant difference in the climatic properties between summer and monsoon seasons, when compared to summer and winter seasons (clear sky, no rain, similar pollution level, and arid environment in both the seasons, except that winter is cooler than summer), in Hyderabad. The condition of weather and temperature were recorded using an application on an Android based smartphone (https://www.accuweather.com/en/in/hyderabad/202190/weather-forecast/202190).

Position of device sensor during measurement

For each location, data were captured aligning the sensor of the spectrometer towards five directions i.e., East, North, West, South, and Up (towards sky). Measurements were repeated twice for each direction, such that a dataset of 200 recordings were produced for analysis in each location (5 directions x 2 repetitions x 5-time points x 2 days x 2 seasons). Figure 2 represents the measurement protocol of the study.

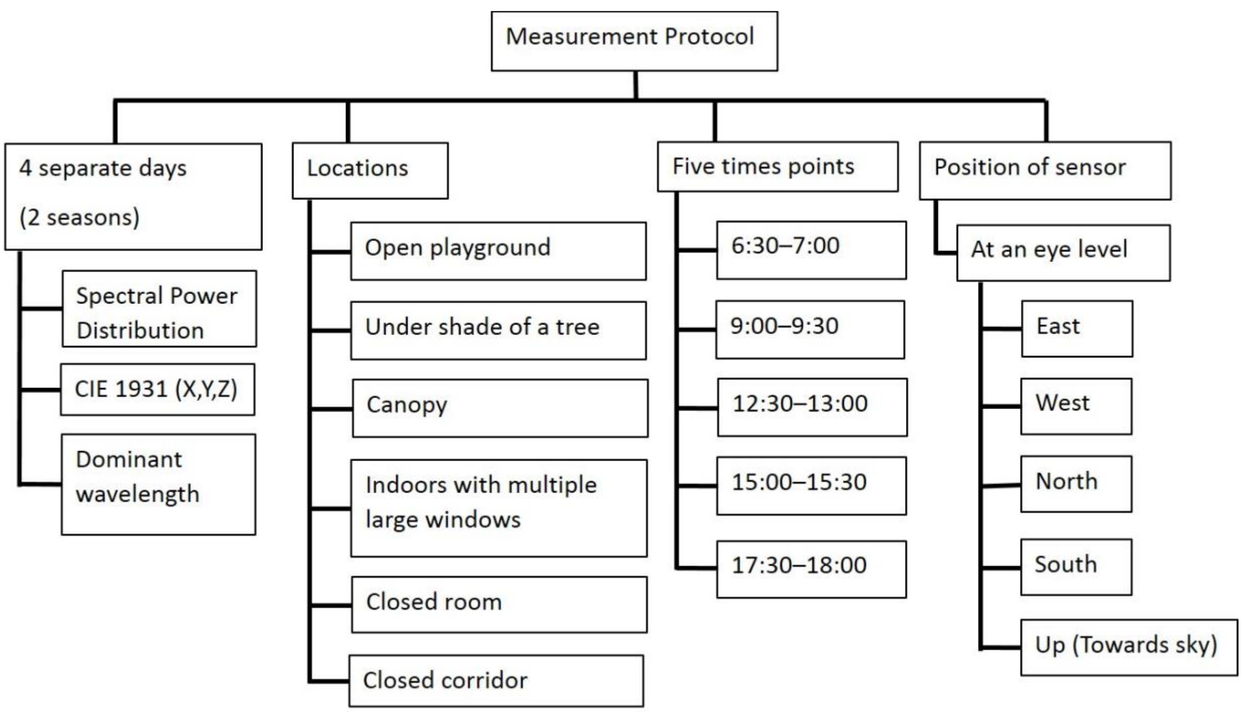

Figure 2. Flowchart of the measurement protocol in each season.

In addition to investigating the spectral composition of an ambient light in different locations, a separate experiment was conducted to understand how the spectral composition of an indoor location varies with increase in illuminance level. The measurements were recorded by placing a spectrometer at a distance of 2, 1, 0.5 and 0.25 metres from the source of light (12 Watt LED).

Statistical analysis

IBM SPSS statistics 20 (SPSS, Inc, Chicago, IL) and Microsoft Excel 2016 (Microsoft Corporation, USA) were used to analyse and plot the graphs respectively. GoCIE software was used to plot CIE 1931 (X,Y,Z) colour space and dominant wavelength.[31] The Shapiro-Wilk test revealed that SPD values at different time points, locations and seasons were not-normally distributed, hence non-parametric tests were used for statistical analyses.

A Kruskal-Wallis test was used to analyse the differences in SPD value among different locations (six locations- three outdoors and three indoors), and Mann-Whitney U test was used for pairwise comparisons. To test whether the SPD value was significantly different across different time points of the day, Friedman test was used with post-hoc analysis using the Wilcoxon signed rank test. The differences between two separate days in each season and between two seasons (average of two separate days was taken for each season) were analysed using Mann-Whitney U test.

The absolute SPD value (raw value) was further categorised to short (wavelengths ranging between 380-500 nm- includes violet, indigo and blue wavelengths), middle (505-565 nm- includes green wavelength) and long (625-780 nm- includes red and near-infrared) wavelengths to understand the distribution of these spectra in the selected locations.[32] This was converted to a percentage form (relative SPD value where the sum of short, middle and long wavelengths was 100%) for ease of comparison across different locations. Considering that blue light is of high interest in the field of myopia, the spectral power of blue wavelength (450-500 nm) was analysed separately. The Friedman test was used to statistically analyse the differences in spectral power among these categories in each of the locations, and pairwise analyses were performed using a Wilcoxon signed rank test.

The SPD value is represented as median (IQR) W/nm/m^2. A P value of <0.05 was considered statistically significant.

Results

Spectral Power Distribution in different locations

The median SPD values across the assessed visible electro-magnetic spectrum (average value of four days-two each from summer and monsoon season) measured in three outdoor and three indoor locations are shown in Table 1. The overall median SPD value (includes data of all four days of both the seasons) in an outdoor location (0.11 [0.09, 0.12]) was 157 times higher than the indoor location (0.0007 [0.0001, 0.001]). In the outdoor locations, the highest SPD value was recorded in an 'open playground' (0.26 [0.21, 0.28]) followed by 'under shade of tree' (0.082 [0.074, 0.090]) and 'canopy' (0.014 [0.012, 0.015], $P<0.01$). In the indoor locations, 'room with multiple windows' recorded a significantly higher SPD (0.019 [0.013, 0.024]) than 'closed room' (0.0009 [0.0002, 0.0015]) and 'closed corridor' (0.0005 [0.0001, 0.0009]) ($P<0.01$). Overall, the median SPD in an 'open playground' was three times higher than 'under shade of tree', 13 times higher than 'canopy', 18 times higher than 'room with multiple windows', 288 times higher than 'closed room', and 520 times higher than the 'closed corridor'.

Table 1. Spectral power distribution in three outdoor and three indoor locations on a different day and seasons.

Spectral power distribution across visible spectrum (W/nm/m^2) [Median (IQR)]								
Locations	Summer season (March)			Monsoon season (July)				
	Day 1	Day 2	Average	Day 3	Day 4	Average	Overall	P-value
Outdoor locations								
Open playground	0.31 (0.25, 0.32)	0.24 (0.19, 0.25)	0.27 (0.21, 0.29)*	0.17 (0.14, 0.19)	0.30 (0.24, 0.32)	0.23 (0.19, 0.26)*	0.26 (0.21, 0.28)	<0.01
Under shade of tree	0.054 (0.050, 0.058)	0.095 (0.079, 0.107)	0.074 (0.067, 0.082)*	0.067 (0.059, 0.075)	0.063 (0.054, 0.07)	0.065 (0.056, 0.073)*	0.082 (0.074, 0.090)	<0.01
Canopy	0.020 (0.014, 0.017)	0.020 (0.018, 0.022)	0.018 (0.016, 0.019)*	0.0075 (0.0065, 0.0086)	0.0076 (0.0065, 0.0087)	0.0076 (0.0065, 0.0086)*	0.014 (0.012, 0.015)	<0.01
Indoor locations								
Rooms with multiple large windows	0.010 (0.007, 0.014)	0.025 (0.016, 0.030)	0.018 (0.012, 0.022)*	0.019 (0.013, 0.024)	0.035 (0.023, 0.042)	0.027 (0.018, 0.033)*	0.019 (0.013, 0.024)	<0.01
Closed room	0.0010 (0.0002, 0.0016)	0.0010 (0.0002, 0.0016)	0.0010 (0.0002, 0.0016)*	0.0009 (0.0002, 0.0015)	0.0009 (0.0002, 0.0015)	0.0009 (0.0002, 0.0015)*	0.00095 (0.0002, 0.0015)	>0.05
Closed corridor	0.0005 (0.0001, 0.0009)	0.0005 (0.0001, 0.0009)	0.0005 (0.0001, 0.0009)*	0.0005 (0.0001, 0.0009)	0.0005 (0.0001, 0.0009)	0.0005 (0.0001, 0.0009)*	0.0005 (0.0001, 0.0009)	>0.05

The P-value indicates the level of statistical significance of the difference in SPD between summer and monsoon seasons.

'' represents statistical significance at the 1% level between two different days in each season (Day 1 vs Day 2 in summer season, and Day 3 vs Day 4 in monsoon season).*

Spectral Power Distribution at different time points of a day

The SPD value varied considerably across different time points of a day (P<0.01) in all three outdoor locations, with the highest value recorded in the middle of the day between 12:30 to 13:00 clock hours (Figure 3). These values were lowest in the morning (6:30-7:00) and the evening hours (17:30-18:00) in all the outdoor locations. In the 'room with multiple windows', highest median SPD was noted in the morning that gradually decreased as the day progressed. The two indoor locations ('closed room' and 'closed corridor') did not exhibit variations in the SPD value across the day, (P>0.05). The median SPD value (average value of four different days) across five different time points in all the six locations are represented in Table S1 in the supplementary file.

Spectral Power Distribution on different days and seasons

The median SPD value measured during two seasons and two different days (i.e., day 1 vs day 2 during summer, and day 3 vs day 4 during monsoon) differed from each other significantly in all the three outdoor locations (summer values higher than monsoon season values by up to 2.5x) and in 'room with multiple windows' (up to 1.84x) (Table 1, $P<0.01$). The two other closed indoor locations (closed room and closed corridor) showed similar SPD values between the two days and seasons (Figure 3). Despite the differences observed between two separate days and seasons, the median SPD in the outdoor locations were always greater than the indoor locations on different days and in both the tested seasons.

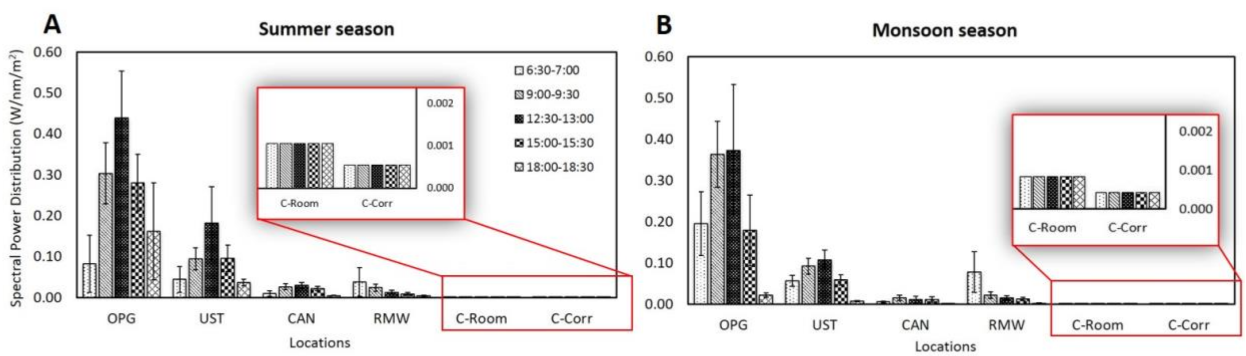

Figure 3. Spectral power distribution in different outdoor and indoor locations across different time points in summer (A; left) and monsoon (B; right) seasons. Error bars represents standard deviations of two separate days in each season. Inset in each panel represents magnified view of closed room and closed corridor. OPG- Open Play Ground, UST- Under shade of tree, CAN- Canopy, RMW- Room with Multiple Windows, C-Room- Closed Room, and C-Corr- Closed Corridor.

Distribution of short, middle, and long wavelengths in different locations

The pattern of the SPD curve of each of the outdoor and indoor locations in summer and monsoon seasons are shown in Figure 4. The SPD curves of the outdoor locations where sun is the source of light are different than that of the indoor locations where artificial lamps are the source of light, and no influence of season was noticed in the pattern of curve. While two of the outdoor locations- 'open playground' and 'under shade of tree', did not show a distinct peak for any of the wavelength of light across the visible electromagnetic spectrum, indicative of similar distribution of short, middle and long wavelengths, two closed indoor locations showed two distinct peaks, one each in the indigo-bluish range and orangish-red range. A steep rise in the SPD curve was noticed in the near Infra-Red (NIR) region in the 'canopy', whereas opposite trend was seen in the 'room with multiple windows' where SPD curve declined towards the near IR range.

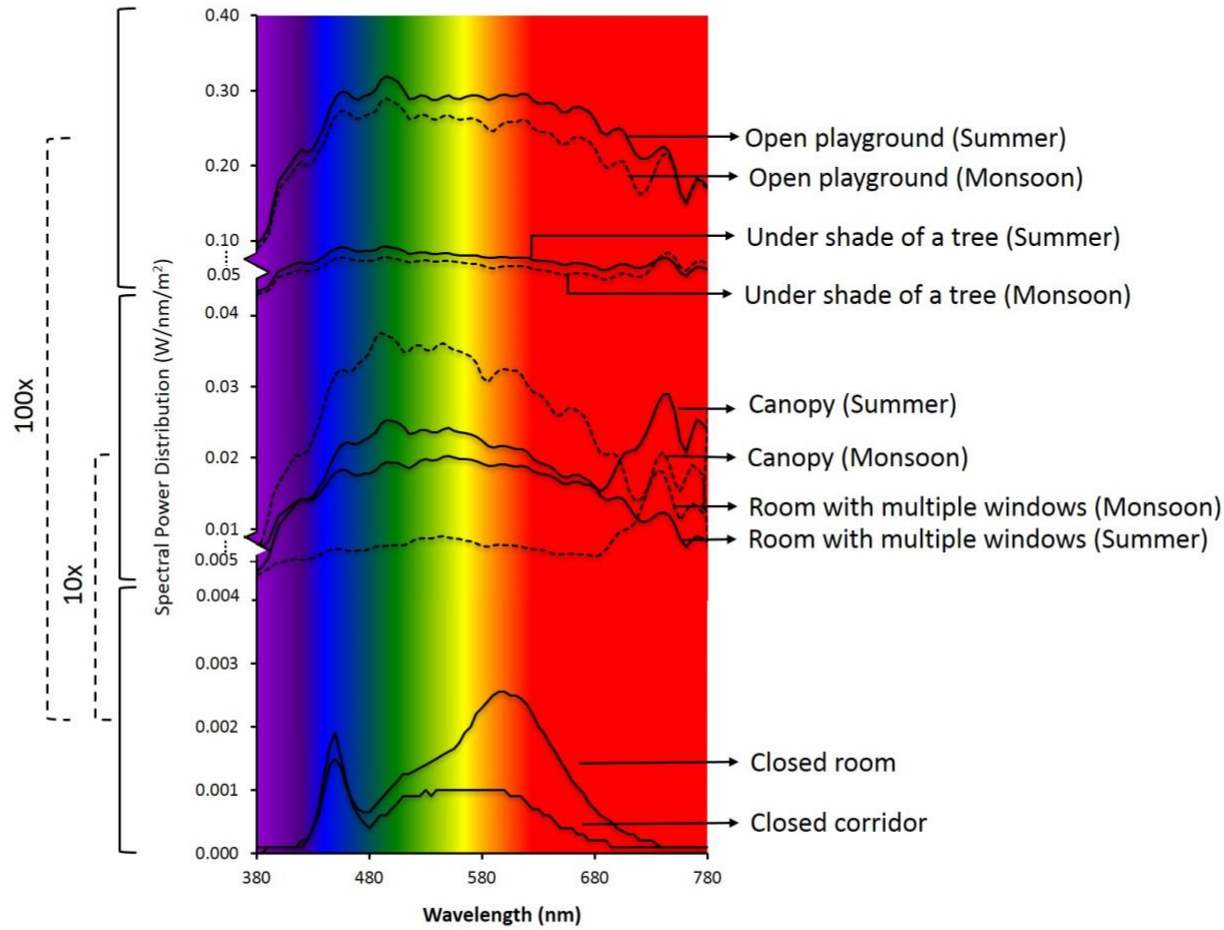

Figure 4. Pattern of spectral power distribution curves of different locations in summer and monsoon seasons. Note, the step-up of the scale on the Y-axis by multiples of 10 from closed indoor locations to ‘room with multiple windows’ and ‘canopy’, and multiples of 100 from closed indoors to ‘under shade of tree’ and ‘open playground’.

In both the outdoor and indoor locations (except canopy), the absolute spectral power and percentage composition of blue (450-500 nm) and middle (505-565 nm) wavelengths were always higher than short (380-500 nm) and long (625-780 nm) wavelengths ($P<0.01$). In ‘canopy’, long wavelengths’ spectral power was higher than other three category of wavelengths ($P<0.01$). Nevertheless, the spectral power of short, middle, long, and blue wavelengths was significantly lower in indoor compared to outdoor locations (Figure 5).

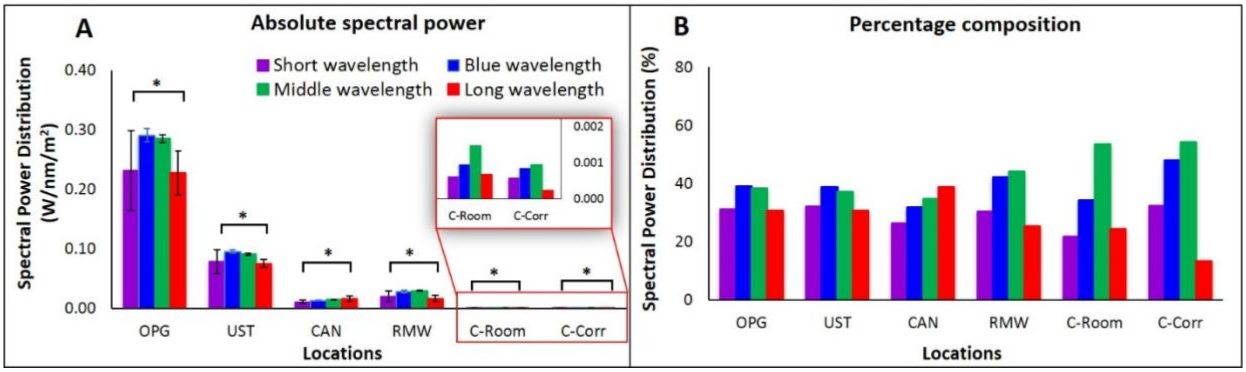

Figure 5. Panel A (Left) represents the spectral power of short, middle, long, and blue wavelength, whereas the percentage composition is shown in panel B (Right). Error bars in panel A represent standard deviation of four separate days. Inset in panel A represents magnified view of closed room and closed corridor. '*' represents statistical significance level of <0.01. OPG- Open Play Ground, UST- Under shade of tree, CAN- Canopy, RMW- Room with Multiple Windows, C-Room- Closed Room, and C-Corr- Closed Corridor

Distribution of short, middle, and long wavelengths at different time points on a day

The diurnal variation in the spectral power of short, middle, and long wavelengths followed a similar trend to that of the overall SPD value (overall spectral power of all the wavelength ranging from 380-780 nm) (Figure 6). While the relative percentage composition of the middle wavelength remained unaffected by time of the day and location, short and long wavelengths varied across the day and locations. For example- in an 'open playground' and 'room with multiple windows', the proportion of long wavelengths was higher than short wavelengths in the morning (6:30-7:00) and evening hours (17:30-18:00).

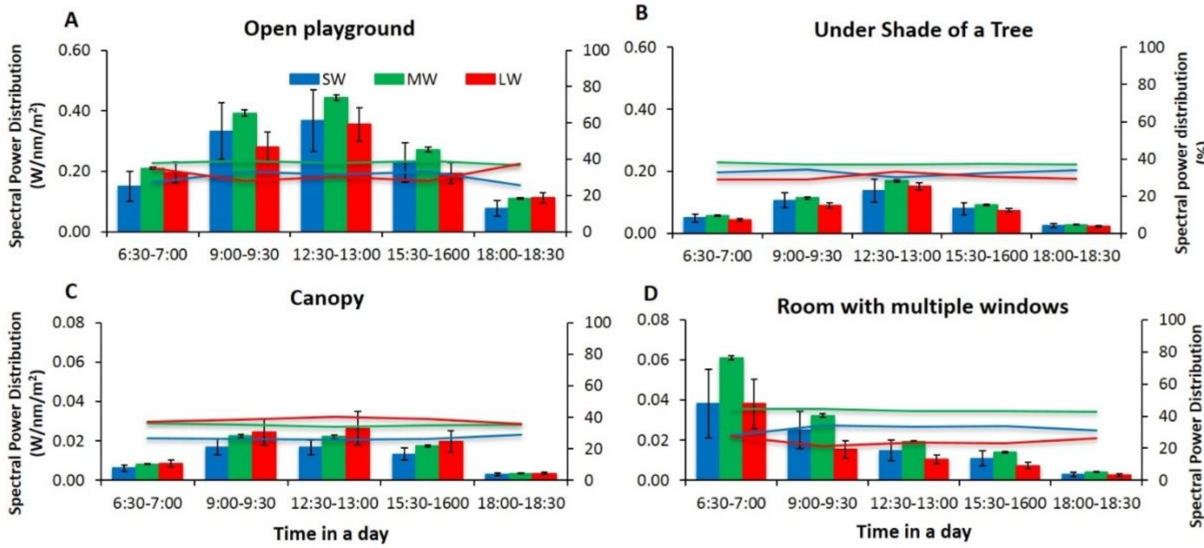

Figure 6. Distribution of short, middle, and long wavelengths across different time points on a day in an open playground (A; top left), under the shade of a tree (B; top right), canopy (C; bottom left) and room with multiple windows (D; bottom right). Bars represent the spectral power distribution (left ordinate), and the line represents the percentage composition (right ordinate) of short, middle, and long wavelengths of light. Note the differences in Y-axis between top and bottom two graphs. SW- Short wavelength, MW- Middle wavelength, and LW- Long wavelength.

The CIE 1931 (X,Y) colour coordinates and dominant wavelength representing six study locations are plotted in a chromaticity diagram, as shown in Figure 7. The colour coordinates of five out of six study locations (all except 'closed room') lie closer to the 'White point', [open playground- (0.34, 0.34), under shade of tree- (0.33, 0.34), canopy- (0.34, 0.35), room with multiple windows- (0.33, 0.36), and closed corridor- (0.33, 0.34)], whereas, the coordinates for 'closed room' lie to the left side of the 'White point' (0.42, 0.39). Similar to the colour coordinates, the dominant wavelength of the same five out of six study locations (except closed room) are located across a different hue of middle wavelength in the spectral locus (Dominant wavelength: open playground -538 nm, under shade of tree- 533 nm, canopy- 519 nm, room with multiple windows- 530 nm, closed corridor- 510, and closed room- 585 nm).

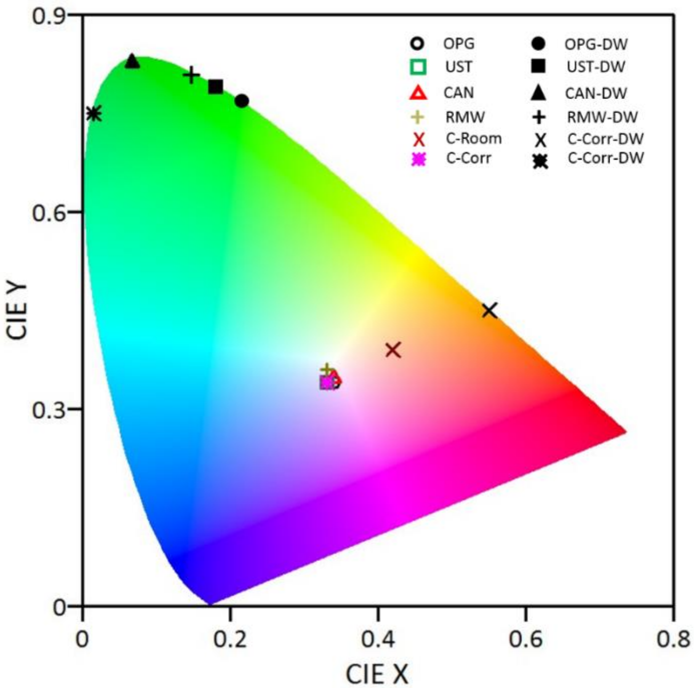

Figure 7. The CIE 1931 (X,Y) colour space chromaticity diagram representing the colour coordinates and dominant wavelength of different outdoor and indoor locations. OPG- Open playground, UST- Under shade of tree, CAN- Canopy, RMW- Room with Multiple Windows, C-Room- Closed Room, C-Corr- Closed Corridor, and DW- Dominant wavelength.

Variation of spectral power distribution with alterations in illuminance level

The illuminance level and median SPD value recorded at a distance of 2, 1, 0.5 and 0.25 metres from the light source were 33, 85, 312 and 751 lux, and 0.00019 [0, 0.00044], 0.00055 [0, 0.0011], 0.002 [0.0003, 0.0043] and 0.005 [0.0008, 0.01] W/nm/m^2, respectively. Interestingly, although the median SPD value showed a positive association with illuminance level in the indoor setting, the percentage composition of short (27 vs 27 vs 28 vs 28 % at 2 vs 1 vs 0.5 vs 0.25 m, respectively), middle (65 vs 62 vs 61 vs 61 %) and long wavelengths (8 vs 10 vs 11 vs 11 %) were similar at all the distances.

Discussion

This study investigated the spectral composition of the visible electromagnetic spectrum in three outdoor and three indoor locations at different time points, different days and different seasons. SPD varied considerably between outdoors and indoors, and as well between outdoor locations. Irrespective of significant diurnal and seasonal variations noted in SPD, the values were always higher in the outdoor compared to indoor locations. With regards to distribution of short, middle and long wavelengths, a similar spectral composition was observed in both the outdoor and indoor locations, with a higher proportion of middle wavelength compared to short and long wavelengths in all the locations, except 'canopy' which exhibited a higher proportion of long wavelengths.

Overall, the SPD value in outdoor locations was 154 times higher than indoors, with the highest SPD noted in an 'open playground' and the lowest in closed indoor locations (open playground > under shade of tree > canopy > room with multiple windows > closed room > closed corridor). In all the outdoor locations, SPD demonstrated a diurnal variation, recording a gradual increase in value from early morning to a maximum level in the middle of the day and dropping in the evening. In 'room with multiple windows', the highest SPD was recorded in the morning time, which gradually decreased as the day progressed, attributing to presence of multiple large sized glass windows facing towards the East direction. In closed indoor locations, i.e., 'closed room' and 'closed corridor', the SPD did not change across different time points, days and seasons, possibly due to fixed artificial source of light used inside closed room and closed corridor (Light Emitting Diode in both the locations). The SPD values exhibiting diurnal and locational variability reported in this study follows a pattern similar to the illuminance level reported by Bhandary et al.[26] who recorded illuminance level in nine outdoor and four indoor locations, and reported a significant variation in illuminance levels among different outdoor locations.

The current study showed a significant seasonal difference in the absolute median SPD value, a finding that corroborates the findings reported by Thorne et al.[29] who investigated daily and seasonal variations in the spectral composition of light exposure in UK. The findings from our study and Thorne et al. reported higher absolute SPD values in summer compared to monsoon (current study) or winter seasons (in the UK). In addition, we noted a similar relative contribution of short (summer vs monsoon: 31 vs 31%), middle (37 vs 38%), long (32 vs 30%) and blue wavelengths (32 vs 30%) in both the seasons. The seasonal differences observed in these studies could possibly be one among many reasons why myopia progression is slower in summer than in the winter.[33-35]

There was a relative reduction in the proportion of shorter wavelengths and increase in the longer wavelengths during early morning (6:30-7:00) and evening hours (17:30-18:00) in an ‘open playground’ and ‘room with multiple windows’, a pattern also observed by Thorne et al.[29]. These differences in relative proportions of different wavelengths could possibly be explained by Rayleigh scattering phenomenon,[36] whereby longer wavelengths of light scatter less, travel longer distances and therefore are present at higher levels than shorter wavelengths. We also found a steep rise in SPD curve in the NIR region, high absolute SPD value, and percentage composition in the longer wavelength and NIR region, under canopy. This could be explained by the fact that healthy leaves absorb spectral irradiance in the photo-synthetically active radiation between 400-700 nm, and has higher reflectance in the NIR radiation >700 nm.[37] The study by Spitschan et al.[27] reported an increase in SPD of shorter wavelengths from daylight to civil twilight in the city area, with no effect on the spectral composition observed in the nautical twilight and night time, possibly attributing to light pollution caused by artificial sources of light. The current study did not find such changes, as we did not record measurements after 18:00.

There is increasing evidence on the protective effect of outdoor light exposure against incident myopia.[38-41] Majority of the published studies that reported association between light and myopia have quantified light exposure using illuminance (lux).[30, 40, 42-44] Ostrin, [30] using an ‘Actiwatch spectrum’ wearable light tracker, recorded broadband white, and monochromatic red, green and blue light exposure in adult emmetropes and myopes aged 21-65 years. The findings of no significant differences in the objective measurements of daily outdoor light exposure to broadband white and monochromatic spectra between the two refractive groups could be attributed to the age range of the participants used by Ostrin in her study. The interactive relationship between exposure to different spectra of light and development of myopia in children is less known. Children are likely to spend most of their time at school (indoors) and playground (outdoors), which exposes them to constantly varying photic environment. Previous studies have shown that myopic children spend less time at outdoors compared to emmetropic children.[12, 42] Considering that the onset of juvenile myopia generally occurs at an early age (before 15 years), it would be worthy to investigate if there exist any difference in the SPD exposure pattern in children, and its association with myopiogenesis.

The current study shows that the pattern of diurnal and locational variability of SPD values are similar to the pattern of variation in illuminance level.[26] This is explained through the findings of our investigation where we assessed the effect of alterations in illuminance level on SPD value and isolated spectral power of short, middle and long wavelengths. The SPD value increased with the increase in illuminance level, but the percentage composition of short, middle and long wavelengths remained same. This presents another question related to protective mechanism of outdoor light exposure against myopia: "Is it the lux level or the spectral power characteristics in isolation, or both, that is protective against myopia?" If spectral power or distribution play a role in myopia prevention, it is possible that certain environments may be more beneficial than others. For example, 'open playground', 'under shade of tree' and 'room with multiple windows' might be beneficial if short-wavelength exposure is important, and locations like a canopy that lacks shorter wavelength might help if longer wavelengths are considered important.

The strength of the current study is the rigour of the measurement protocol itself. The sensor of the spectrometer recorded data in five different directions at an eye level with two repetitions in each direction, on two different days and during two different seasons. This produced a total of 200 measurements in each outdoor and indoor location. The multi-directionality of the measurements was based on the fact that children could face any direction while playing. A possible limitation is the location of data collection (a single location in the southern part of India). Given that there is variation in temperature, weather, altitude, pollution level, aerosols etc in different parts of the world, it could be possible that SPD observed in Hyderabad may not be generalizable to other parts of the world. Likewise, the current study explored the spectral composition of ambient light in different outdoor and indoor locations, and did not investigate the association between SPD and myopia in these locations. Further longitudinal studies should be conducted in children to explore cause-effect and dose-response relationship between exposure to different spectral composition of ambient light and myopia. In an indoor location, aside from the measured values obtained from artificial source of indoor light, children's retinal illumination is also affected by digital devices used (e.g., phone, tablet, laptop etc). This was not explored in the current study, and we recommend future studies should investigate this aspect.

In conclusion, we observed that the overall SPD of ambient light, and the spectral power of short, middle and long wavelength of light varies with location, time, day and season. Irrespective of such variation, SPD in outdoor locations was always higher than that of indoor locations. This study also highlights that the relative percentage composition of short, middle, long and blue wavelengths of light are similar across outdoor and indoor locations, but significant variability exists in absolute spectral power (outdoors>indoors). This study lays the foundations to improve our understanding of how spectral composition varies across different locations, time, days and seasons. Further investigations are warranted to understand its causal association with myopia. Among many hypotheses related to protective mechanism of outdoor light exposure against myopia, role of SPD in myopia control should be investigated further.

Competing interest: None

Contributors: PKV conceptualized and made funding available; **PKV and RD** designed methodology; **RD** arranged resource, performed data collection, analysed data, prepared first draft of manuscript and worked on subsequent revisions; **PKV, JGL, BH and RS** supervised and reviewed the manuscript. All the authors have approved the final manuscript.

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