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

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15

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19 **Running title:** Spectral composition of an ambient light

20 **Keywords:** Ambient light, outdoor, RGB, spectral composition, wavelength, myopia

21 **Abstract**

22 **Purpose**

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

27 **Methods**

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

34 **Results**

35 The overall median SPD (IQR [25th-75th percentile] W/nm/m²) across three outdoor locations (0.11
36 [0.09,0.12]) was 157 times higher than indoor locations (0.0007 [0.0001,0.001]). A considerable locational,
37 diurnal and seasonal variation was observed in the distribution of median SPD value, with a highest value
38 recorded in the 'open playground' (0.27 [0.21,0.28]) followed by 'under shade of tree' (0.083[0.074,0.09]),
39 'canopy' (0.014[0.012,0.015]), and 'room with multiple windows' (0.023[0.015,0.028]). The relative
40 percentage composition of short, middle and long wavelengths was similar in both the outdoor and indoor
41 locations, with the proportion of middle wavelength significantly higher (P<0.01) than short and long
42 wavelengths in all the locations except canopy.

43 **Conclusion**

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

49 **Keypoints**

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

56 **Introduction**

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

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

76 Spitschan et al.²⁷ investigated the spectral composition of ambient light in USA reporting significant
77 variations in the spectral power between rural and urban areas, attributing to the possible light pollution
78 by artificial sources of light in the urban areas. Variation of solar spectrum in different seasons was

79 investigated as a function of 'average photon energy' (defined as a ratio of total irradiance contained in
80 the spectrum to total photon flux density) by Bangar et al.²⁸, and reported average photon energy ranged
81 between 1.70 to 2.01 eV across the year, with monsoon season having the highest average photon energy
82 (1.90 to 1.98 eV).

83 The pattern of ambient red, green and blue (RGB) spectrum exposure in humans was investigated by two
84 studies.^{29, 30} Thorne et al.²⁹ reported daily and seasonal variation in the relative contribution (%) of red,
85 green and blue spectrum exposure in young adults living in England. Significant difference in the relative
86 exposure of blue light spectrum was observed between the seasons, especially in the evening, with a
87 significantly higher contribution in the summer's evening compared to winter's evening. Likewise, using a
88 cross-sectional study design, Ostrin³⁰ recorded the exposure of RGB spectrum in emmetropes and
89 myopes, and reported no difference in the irradiance level between the two cohorts. Both studies used a
90 wearable light tracker (Actiwatch-RBG monitors and Actiwatch-L monitors, Philips, USA) to record
91 exposure to various light spectra and had no control over the movement and/or location of the
92 participants. The latter is important as the distribution of spectral composition of ambient light in various
93 outdoor and indoor locations where children spend most of their time is unknown.

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

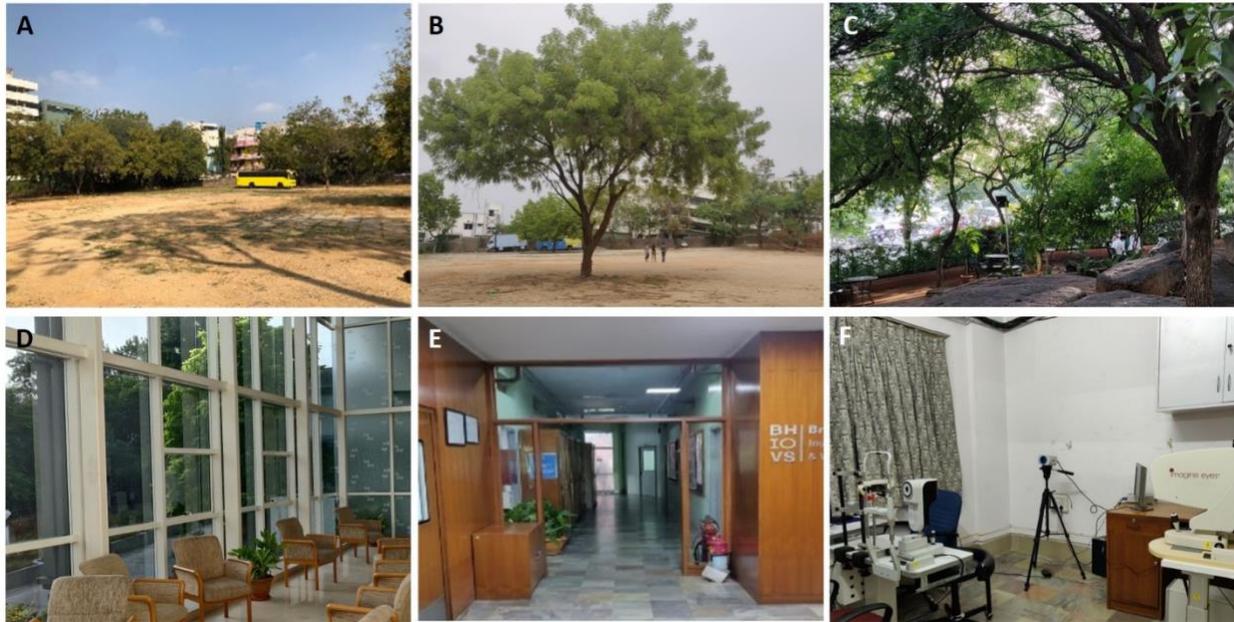
102 **Methods**

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

121 **Locations where measurements were recorded**

122 The spectral composition was recorded in three outdoor locations, namely 'open playground', 'under
123 shade of tree' and 'canopy', and three indoor locations, namely 'room with multiple windows', 'closed
124 room' and 'closed corridor' located in and around the institute premise. The characteristics of these

125 locations are detailed elsewhere²⁶ except 'closed room' and 'closed corridor'. The 'closed room' measured
126 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
127 'closed corridor' measured 17.6 x 2 x 2.9 m with a LED light source. Figure 1 shows the pictorial
128 representation of these locations.



129
130 Figure 1. Outdoor (panel A-C) and indoor (panel D-F) locations. A- Open playground, B- Under shade of
131 tree, C- Canopy, D- Room with multiple windows, E- Closed corridor, and F- Closed room.

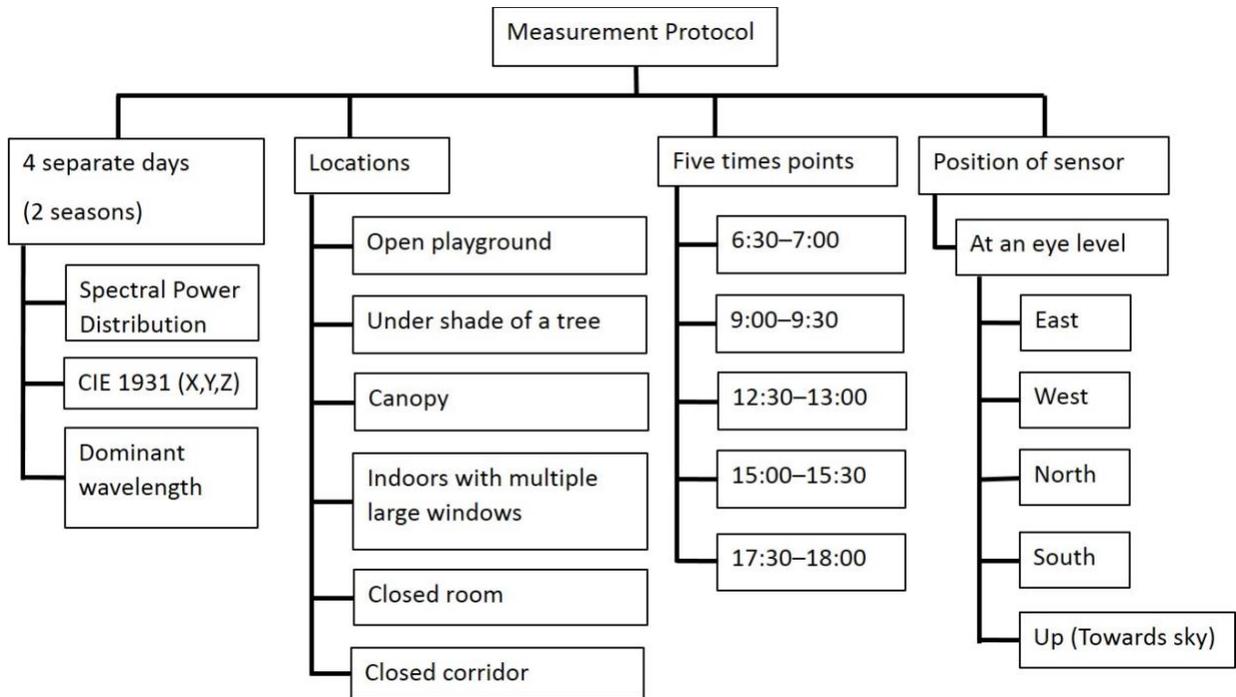
132 Time of a day when measurements were recorded

133 Measurements in all the six locations were recorded five times across a day (6:30-7:00, 9:00-9:30, 12:30-
134 13:00, 15:00-15:30, and 17:30-18:00 clock hours) within a 30-minute window period for each time point
135 across all locations. The position and height of the tripod were fixed for each location throughout the
136 measurement period. To observe the temporal change in spectral composition with days and seasons,
137 measurements were recorded on four separate days, two days in each of the two different seasons. These
138 included i) summer- March 2021 (March-June) with clear sky and arid environment, and ii) monsoon- July
139 2021 (July-October) with cloud cover and high humidity. The monsoon season was selected instead of

140 winter because of the significant difference in the climatic properties between summer and monsoon
 141 seasons, when compared to summer and winter seasons (clear sky, no rain, similar pollution level, and
 142 arid environment in both the seasons, except that winter is cooler than summer), in Hyderabad. The
 143 condition of weather and temperature were recorded using an application on an Android based
 144 smartphone (<https://www.accuweather.com/en/in/hyderabad/202190/weather-forecast/202190>).

145 **Position of device sensor during measurement**

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



151
 152 Figure 2. Flowchart of the measurement protocol in each season.

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

157 **Statistical analysis**

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

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

169 The absolute SPD value (raw value) was further categorised to short (wavelengths ranging between 380-
170 500 nm- includes violet, indigo and blue wavelengths), middle (505-565 nm- includes green wavelength)
171 and long (625-780 nm- includes red and near-infrared) wavelengths to understand the distribution of
172 these spectra in the selected locations.³² This was converted to a percentage form (relative SPD value
173 where the sum of short, middle and long wavelengths was 100%) for ease of comparison across different
174 locations. Considering that blue light is of high interest in the field of myopia, the spectral power of blue
175 wavelength (450-500 nm) was analysed separately. The Friedman test was used to statistically analyse the

176 differences in spectral power among these categories in each of the locations, and pairwise analyses were
177 performed using a Wilcoxon signed rank test.

178 The SPD value is represented as median (IQR) W/nm/m². A P value of <0.05 was considered statistically
179 significant.

180 **Results**

181 **Spectral Power Distribution in different locations**

182 The median SPD values across the assessed visible electro-magnetic spectrum (average value of four days-
183 two each from summer and monsoon season) measured in three outdoor and three indoor locations are
184 shown in Table 1. The overall median SPD value (includes data of all four days of both the seasons) in an
185 outdoor location (0.11 [0.09, 0.12]) was 157 times higher than the indoor location (0.0007 [0.0001,
186 0.001]). In the outdoor locations, the highest SPD value was recorded in an 'open playground' (0.26 [0.21,
187 0.28]) followed by 'under shade of tree' (0.082 [0.074, 0.090]) and 'canopy' (0.014 [0.012, 0.015], $P < 0.01$).
188 In the indoor locations, 'room with multiple windows' recorded a significantly higher SPD (0.019 [0.013,
189 0.024]) than 'closed room' (0.0009 [0.0002, 0.0015]) and 'closed corridor' (0.0005 [0.0001, 0.0009])
190 ($P < 0.01$). Overall, the median SPD in an 'open playground' was three times higher than 'under shade of
191 tree', 13 times higher than 'canopy', 18 times higher than 'room with multiple windows', 288 times higher
192 than 'closed room', and 520 times higher than the 'closed corridor'.

193 Table 1. Spectral power distribution in three outdoor and three indoor locations on a different day and
 194 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

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

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

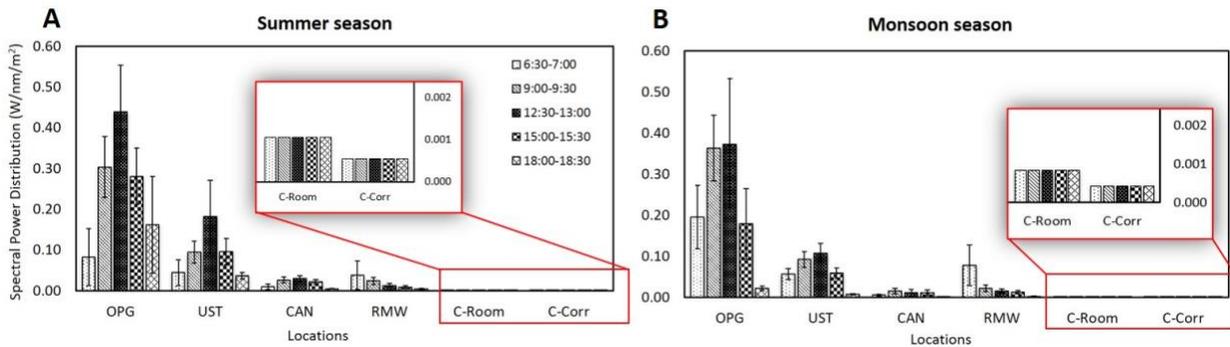
199 **Spectral Power Distribution at different time points of a day**

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

206 (average value of four different days) across five different time points in all the six locations are
207 represented in Table S1 in the supplementary file.

208 Spectral Power Distribution on different days and seasons

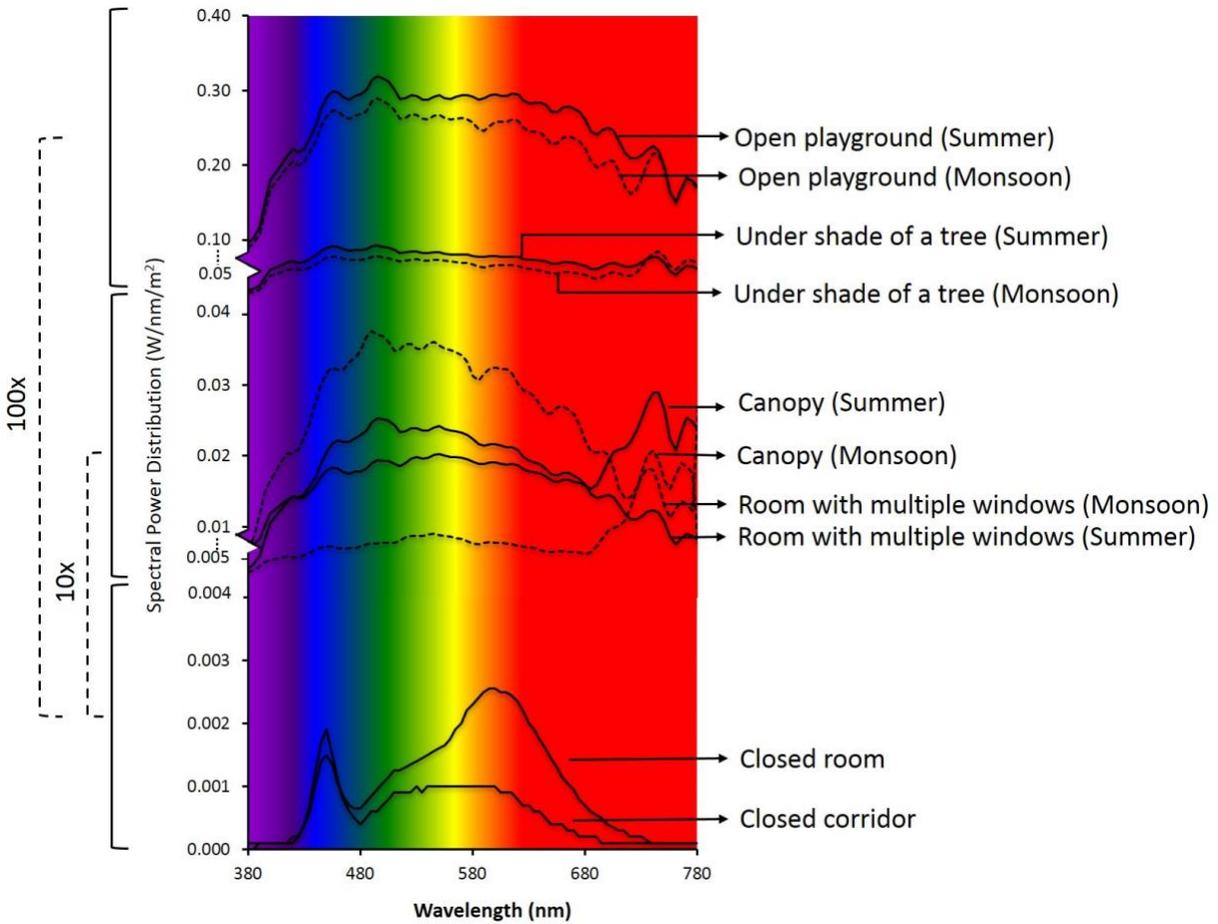
209 The median SPD value measured during two seasons and two different days (i.e., day 1 vs day 2 during
210 summer, and day 3 vs day 4 during monsoon) differed from each other significantly in all the three outdoor
211 locations (summer values higher than monsoon season values by up to 2.5x) and in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



216
217 Figure 3. Spectral power distribution in different outdoor and indoor locations across different time points
218 in summer (A; left) and monsoon (B; right) seasons. Error bars represents standard deviations of two
219 separate days in each season. Inset in each panel represents magnified view of closed room and closed
220 corridor. OPG- Open Play Ground, UST- Under shade of tree, CAN- Canopy, RMW- Room with Multiple
221 Windows, C-Room- Closed Room, and C-Corr- Closed Corridor.

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

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

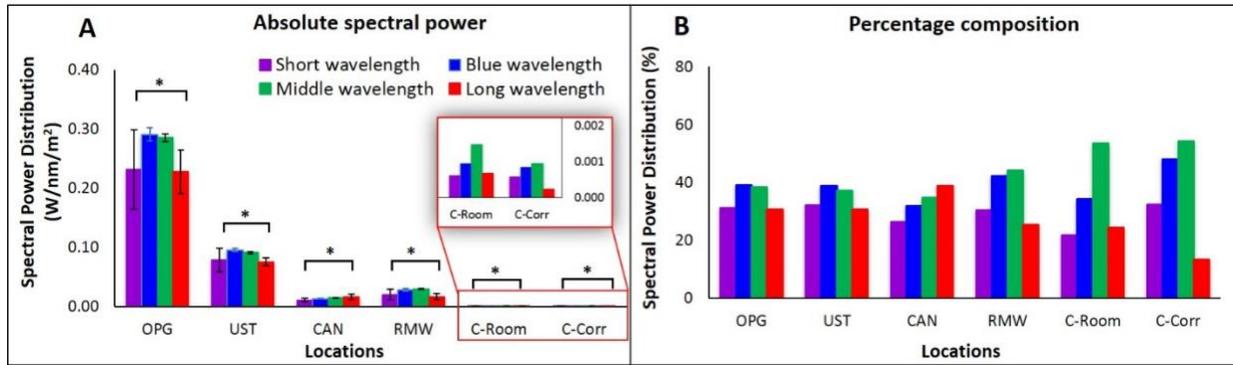


233

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

238

239 In both the outdoor and indoor locations (except canopy), the absolute spectral power and percentage
 240 composition of blue (450-500 nm) and middle (505-565 nm) wavelengths were always higher than short
 241 (380-500 nm) and long (625-780 nm) wavelengths ($P < 0.01$). In 'canopy', long wavelengths' spectral power
 242 was higher than other three category of wavelengths ($P < 0.01$). Nevertheless, the spectral power of short,
 243 middle, long, and blue wavelengths was significantly lower in indoor compared to outdoor locations
 (Figure 5).

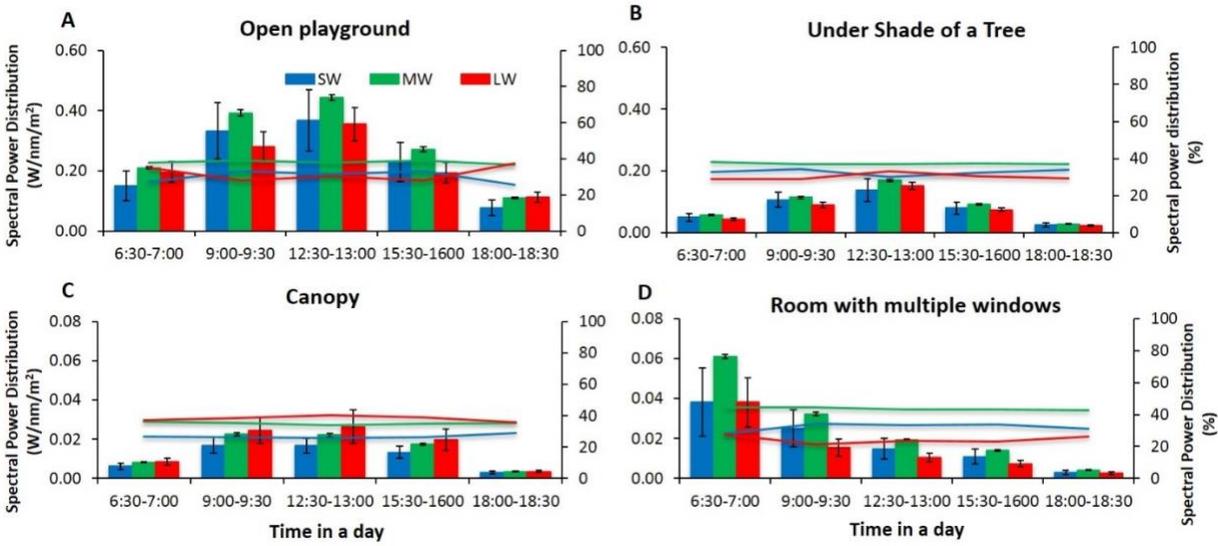


244

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

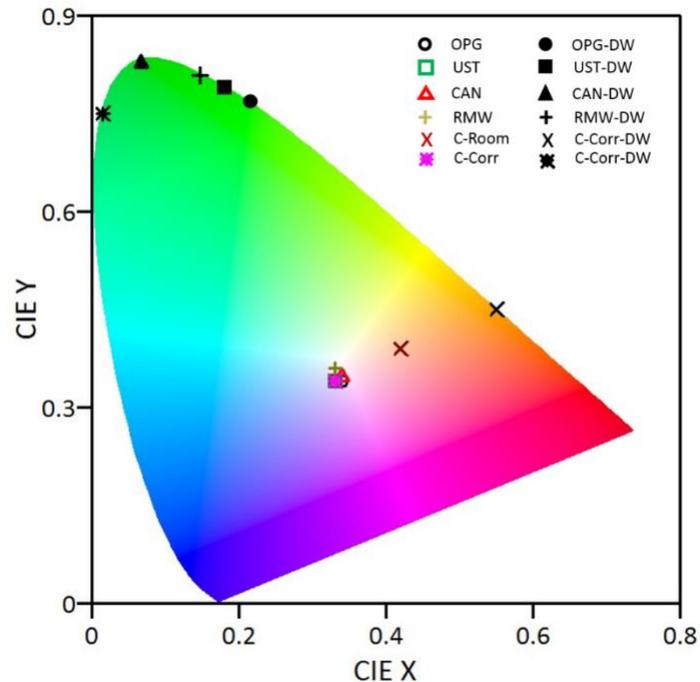
251 **Distribution of short, middle, and long wavelengths at different time points on a day**

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



258
 259 Figure 6. Distribution of short, middle, and long wavelengths across different time points on a day in an
 260 open playground (A; top left), under the shade of a tree (B; top right), canopy (C; bottom left) and room
 261 with multiple windows (D; bottom right). Bars represent the spectral power distribution (left ordinate),
 262 and the line represents the percentage composition (right ordinate) of short, middle, and long
 263 wavelengths of light. Note the differences in Y-axis between top and bottom two graphs. SW- Short
 264 wavelength, MW- Middle wavelength, and LW- Long wavelength.

265 The CIE 1931 (X,Y) colour coordinates and dominant wavelength representing six study locations are
 266 plotted in a chromaticity diagram, as shown in Figure 7. The colour coordinates of five out of six study
 267 locations (all except 'closed room') lie closer to the 'White point', [open playground- (0.34, 0.34), under
 268 shade of tree- (0.33, 0.34), canopy- (0.34, 0.35), room with multiple windows- (0.33, 0.36), and closed
 269 corridor- (0.33, 0.34)], whereas, the coordinates for 'closed room' lie to the left side of the 'White point'
 270 (0.42, 0.39). Similar to the colour coordinates, the dominant wavelength of the same five out of six study
 271 locations (except closed room) are located across a different hue of middle wavelength in the spectral
 272 locus (Dominant wavelength: open playground -538 nm, under shade of tree- 533 nm, canopy- 519 nm,
 273 room with multiple windows- 530 nm, closed corridor- 510, and closed room- 585 nm).



274

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

279 **Variation of spectral power distribution with alterations in illuminance level**

280 The illuminance level and median SPD value recorded at a distance of 2, 1, 0.5 and 0.25 metres from the
 281 light source were 33, 85, 312 and 751 lux, and 0.00019 [0, 0.00044], 0.00055 [0, 0.0011], 0.002 [0.0003,
 282 0.0043] and 0.005 [0.0008, 0.01] W/nm/m², respectively. Interestingly, although the median SPD value
 283 showed a positive association with illuminance level in the indoor setting, the percentage composition of
 284 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
 285 long wavelengths (8 vs 10 vs 11 vs 11 %) were similar at all the distances.

286 **Discussion**

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

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

308 The current study showed a significant seasonal difference in the absolute median SPD value, a finding
309 that corroborates the findings reported by Thorne et al.²⁹ who investigated daily and seasonal variations
310 in the spectral composition of light exposure in UK. The findings from our study and Thorne et al. reported
311 higher absolute SPD values in summer compared to monsoon (current study) or winter seasons (in the
312 UK). In addition, we noted a similar relative contribution of short (summer vs monsoon: 31 vs 31%), middle
313 (37 vs 38%), long (32 vs 30%) and blue wavelengths (32 vs 30%) in both the seasons. The seasonal
314 differences observed in these studies could possibly be one among many reasons why myopia progression
315 is slower in summer than in the winter.³³⁻³⁵

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

329 There is increasing evidence on the protective effect of outdoor light exposure against incident myopia.³⁸⁻
330 ⁴¹ Majority of the published studies that reported association between light and myopia have quantified
331 light exposure using illuminance (lux).^{30, 40, 42-44} Ostrin,³⁰ using an 'Actiwatch spectrum' wearable light

332 tracker, recorded broadband white, and monochromatic red, green and blue light exposure in adult
333 emmetropes and myopes aged 21-65 years. The findings of no significant differences in the objective
334 measurements of daily outdoor light exposure to broadband white and monochromatic spectra between
335 the two refractive groups could be attributed to the age range of the participants used by Ostrin in her
336 study. The interactive relationship between exposure to different spectra of light and development of
337 myopia in children is less known. Children are likely to spend most of their time at school (indoors) and
338 playground (outdoors), which exposes them to constantly varying photic environment. Previous studies
339 have shown that myopic children spend less time at outdoors compared to emmetropic children.^{12, 42}
340 Considering that the onset of juvenile myopia generally occurs at an early age (before 15 years), it would
341 be worthy to investigate if there exist any difference in the SPD exposure pattern in children, and its
342 association with myopiogenesis.

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

354 The strength of the current study is the rigour of the measurement protocol itself. The sensor of the
355 spectrometer recorded data in five different directions at an eye level with two repetitions in each

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

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

379 **Competing interest:** None

380

381 **Contributors:** PKV conceptualized and made funding available; PKV and RD designed methodology; RD
382 arranged resource, performed data collection, analysed data, prepared first draft of manuscript and
383 worked on subsequent revisions; PKV, JGL, BH and RS supervised and reviewed the manuscript. All the
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385

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