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Light Intensity in Nursery Schools: A Possible Factor in Refractive Development

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Purpose: Increased levels of outdoor light have been found to be associated causally with decreased rates of myopia. The goal of this study was to measure the effect of indoor nursery school light intensity on refraction of preschool children in Israel.

Methods: A total of 1596 children aged 4 to 5 years from 27 nursery schools were examined. Light intensity was tested with a luxmeter device (Lux) inside and outside the nursery school. Noncycloplegic refractions were measured with the PlusOptix vision A09 screening device. Data analysis was performed using Pearson coefficients, chi-square tests for proportions and ANOVA tests by tertiles of illuminance.

Results: This study included 1131 kindergarten children with a mean age of 4.87 ± 0.33 years, of which 571 were female (50.5%). The mean light intensity of the low, medium, and high intensity groups differed significantly (ANOVA $P < 0.001$) at 359 ± 2.64 lux (range 264–431), 490 ± 2.21 lux (range 432–574), and 670.76 ± 3.73 lux (range 578–804), respectively. Mean spherical equivalent (SE) was +0.56 ± 0.03D for the low-intensity group, +0.73 ± 0.03D for the medium lux group, and +0.89 ± 0.03D for the high-intensity group (ANOVA $P < 0.001$). The low intensity group had 42.1% of children with zero refraction or less, while the high-intensity group had 19.3%.

Conclusion: In the nursery schools, lower amounts of illumination were associated with less hyperopic refractive error. As the low hyperopic reserve is a risk factor for developing myopia, this finding needs to be followed up to establish whether this association reflects a causal relationship, which could be modulated for the prevention of myopia.

Key Words: hyperopic reserve, indoor lighting, kindergartens, myopia

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Ambient light in school buildings has been a subject of interest for many years as exposure to daylight has shown to be closely associated with improvement in student performance and promotion of better health.[1] The nursery schools in Israel are not built to a standard design, and there are no well-defined standards of illumination. The regulations suggest only a minimum level of 300 lux indoors. Moreover, some of the nursery schools are located in well-designed community buildings, while others are located in private houses with provisional conditions. The illumination in nursery schools, in which children spend most of their diurnal hours, might have a great impact on their ocular health and refractive development since the light environment is known to affect refraction.[2–6] In Israel, during nursery school hours, children spend 7 to 8 hours indoors, with less than a 1-hour outdoor break, 6 days a week, 11 months a year. Thus, children spend a majority of the available weekly diurnal time in nursery schools.

Several studies have shown that children who spend more time outdoors have a lower incidence of myopia.[5,7–9] Many studies have been performed on school children studying the subjective and objective assessment of time spent outdoors and determining the light intensity necessary for reducing the incidence of myopia.[7,10] A meta-analysis has shown a dose-response relationship of outdoor exposure over myopia, and that 10 to 14 hours a week, or 2 hours per day outdoors could reduce the incidence and progression of school myopia associated with low outdoor exposure and high demand of near-work.[7]

Near-work has long been considered an environmental risk factor for the development of myopia, mainly because of the association with educational performance and close-work demands.[11,12] However, it has been shown that a myopic shift toward negative refraction may start before children begin reading at the age of 6 years old. Up to this age, children tend to have stable refraction in the hyperopic range of +1.25 diopters after an infantile phase of emmetropization.[13–16]

At kindergarten age, refractive error screening is performed for early diagnosis of amblyopia and high refractive errors, since there is evidence that treatment before age 5 leads to better vision in those cases. Since ambient light affects refractive development, this study was developed to assess a possible relationship between indoor illumination in nursery schools and refractive error.

METHODS

This cross-sectional study was designed to correlate refraction with ambient light in the kindergartens of northern Israel. All

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study procedures were approved by the Hillel Yaffe Medical Center review boards in 2016. The study included children aged 4 to 5 years who resided in several villages in the east of the city of Hadera. Vision screening in the nursery schools was performed from November to December 2016 by 3 optometrists.

Instrument-based Vision Screening

PlusOptix A09 (PlusOptix GmbH, Nuremberg, Germany) a handheld device, has been designed to screen children for pupil diameter, noncycloplegic refractive error, and ocular alignment using internal software. The testing environment varied depending on space availability, but was typically conducted in a dimly lit room to maximize pupil size for measurements as suggested in the instruction manual. The device produced light and noise to attract the child's attention and fixation on the camera.

The PlusOptix autorefractor was placed at a distance of 1 meter in front of each patient, and measurements were taken by a trained optometrist. The fixation target of the instrument was designed as a smiley face on the camera. Once the start button was pressed, the smiley face was automatically lit, and a warble sound could be heard to draw the child's attention to the camera. The children were asked to gaze at the nose of the smiley face on the camera during the test. Then the camera was moved slightly (within ±50 mm) until green circles were evident around both pupils on the monitor screen, which was followed by automatic measurement. The results displayed on the monitor were: spherical refraction ranging from −7.00 D to +5.00 D in 0.25 D increments; cylindrical values ranging from −7.00 D to +5.00 D in 0.25 D increments with axis in 1° to 180°; and pupil size from 4.0 mm – 8.0 mm in 0.1 mm increments.

For each of the 27 nursery schools, vision screening was completed in 1 day in the morning hours of 9 am to 1 pm. Spherical equivalent refraction (SE) was calculated as spherical diopters (D) plus one-half cylindrical diopters using data from the PlusOptix A09 autorefractor. Because of the high correlation between the right and left eyes, only data from the right eye were presented ($P < 0.001$).

Nursery School Construction and Ambient Light

The architectural design of nursery schools in Israel includes a large gathering room used by the children, extra rooms used by the staff, kitchen, bathroom, and a play yard. The number of windows varies from none to multiple windows in the large room. Indoor activity is mostly performed in the large room for eating, playing, and resting; however, there are no official sleeping hours. Outdoors activity takes place at 11:30 AM for 30 minutes, where children play under the shade or the sun.

A luxmeter (Lutron LX-101A, Lutron Electronics Co Inc) was used to examine light intensity in nurseries at 5 points (4 peripheral corners and the center of the gathering room) and outdoors. It was performed by a single optometrist who performed the measurements in April 2017 from 10 AM to 12 PM.

Statistical Analysis

Data gathered from the subjects in each school were recorded anonymously in an excel database with the age, gender, pupil diameter, and noncycloplegic refractive error of each eye. Refractive error was considered as the dependent variable and ANOVA test for tertiles of illuminance was performed, with a value of $P < 0.05$ taken as the cut-off for statistical significance. Tertiles were arranged by grouping children from different kindergartens in order of illuminance. ANOVA tests by groups were performed to explore the association between refraction and ambient illumination. A linear regression analysis was made for luminance versus refractive error, and chi-square tests were used for proportions. Statistical significance was set at $P < 0.05$ and all analyses were performed using SPSS version 25 (IBM, US).

RESULTS

This study initially enrolled 1596 children aged 4 to 5 years. We later excluded 465 children because we were unable to obtain an estimated refractive error. This was either related to the child's poor cooperation or to the fact that the PlusOptix A09 did not provide a computer printout with a refraction estimate despite several attempts. In our results, we included 1131 children with a mean age of 4.87 ± 0.33 years (50.5% were female).

Indoor and Outdoor Ambient Light

Nursery school light intensity ranged from 264 lux to 804 lux. After the large gathering rooms of the 27 kindergartens were sorted by light intensity, 3 groups were formed. This included low, medium, and high illuminance groups composed of 330 children (29.2%), 434 children (38.4%), and 367 children (32.5%), respectively ($P < 0.001$, Table 1). In each group, light was evenly spread in the large gathering room, as light intensity between the center and periphery of the rooms was strongly correlated (correlation between central luminance and average luminance across rooms; r = 0.954, $P < 0.001$, Figure 1). Thus, we reported only the association between central luminance and refractive error. Light intensity had a mean value of 519.51 ± 137.81 lux (kurtosis -0.558, skewness 0.396). The mean light intensity of the low, medium, and high intensity groups was significantly different (ANOVA $P < 0.001$) at 359 ± 2.64 lux (range 264–431), 490 ± 2.21 lux (range 432–574), and 670.76 ± 3.73 lux (range 578–804), respectively. Mean light intensity outdoors was 6,692 ± 2807 lux in the shade and 95,577 ± 15,577 lux in the sun.

Refraction

The mean SE for the right eyes was +0.74 ± 0.65 D. The mean SE of the light intensity groups is depicted in Figure 2 where the higher the intensity, the greater the mean SE. Mean SE was +0.56 ± 0.03 D for the low-intensity group, +0.73 ± 0.03 D for the medium lux group, and +0.89 ± 0.03 D for the high-intensity group (ANOVA $P < 0.001$). Figure 3 shows the positive correlation between spherical equivalent and central indoor illuminance ($P < 0.001$). In Figure 3, it can be seen that Plano refraction or less was more frequent in children reared in lower illuminance. Table 2 shows the percentage of children with mean SE of Plano

Table 1. Mean Illuminance (SD) of the central and mean lux by tertiles

	Low Illuminance	Median Illuminance	High Illuminance
n=	330	434	367
Central Lux	381.8 ± 99.2	496.3 ± 56.7	670.8 ± 71.6
Mean Lux (Periphery)	355.3 ± 86.8	441.5 ± 62.7	579.8 ± 84.9
Periphery1	351.2 ± 87.0	453.9 ± 68.2	571.8 ± 73.1
Periphery2	364.4 ± 82.2	445.0 ± 81.5	558.4 ± 80.1
Periphery3	361.4 ± 86.2	428.8 ± 80.1	606.3 ± 97.1
Periphery4	345.7 ± 91.9	440.3 ± 60.9	581.7 ± 89.3

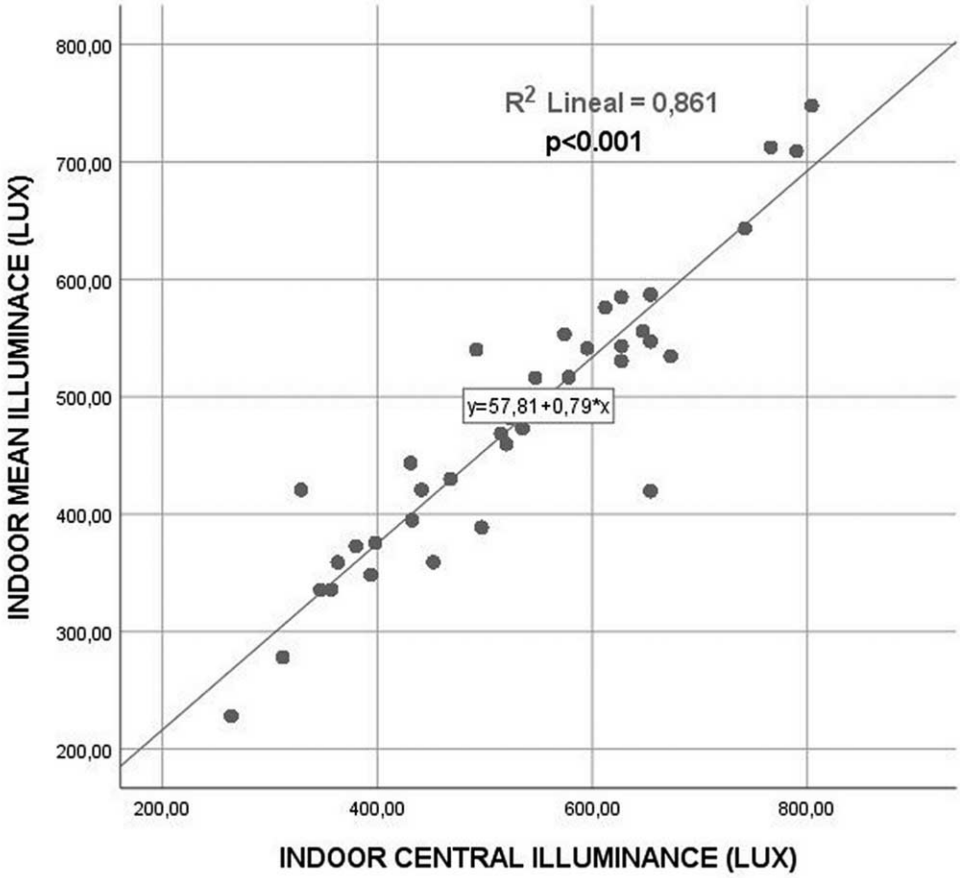

FIGURE 1. Scatterplot with the high correlation between central illuminance and mean peripheral illuminance.

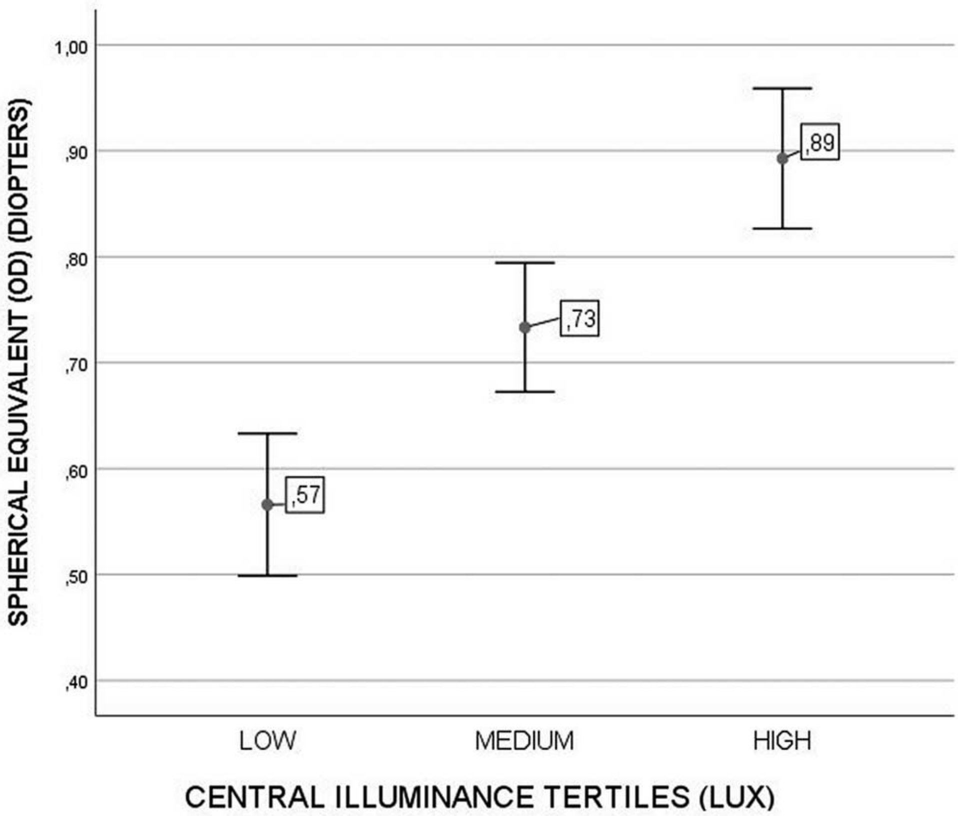

FIGURE 2. Mean and 95% confidence intervals (whiskers) of the spherical equivalent for the 3 illuminance groups (ANOVA $P < 0.0001$).

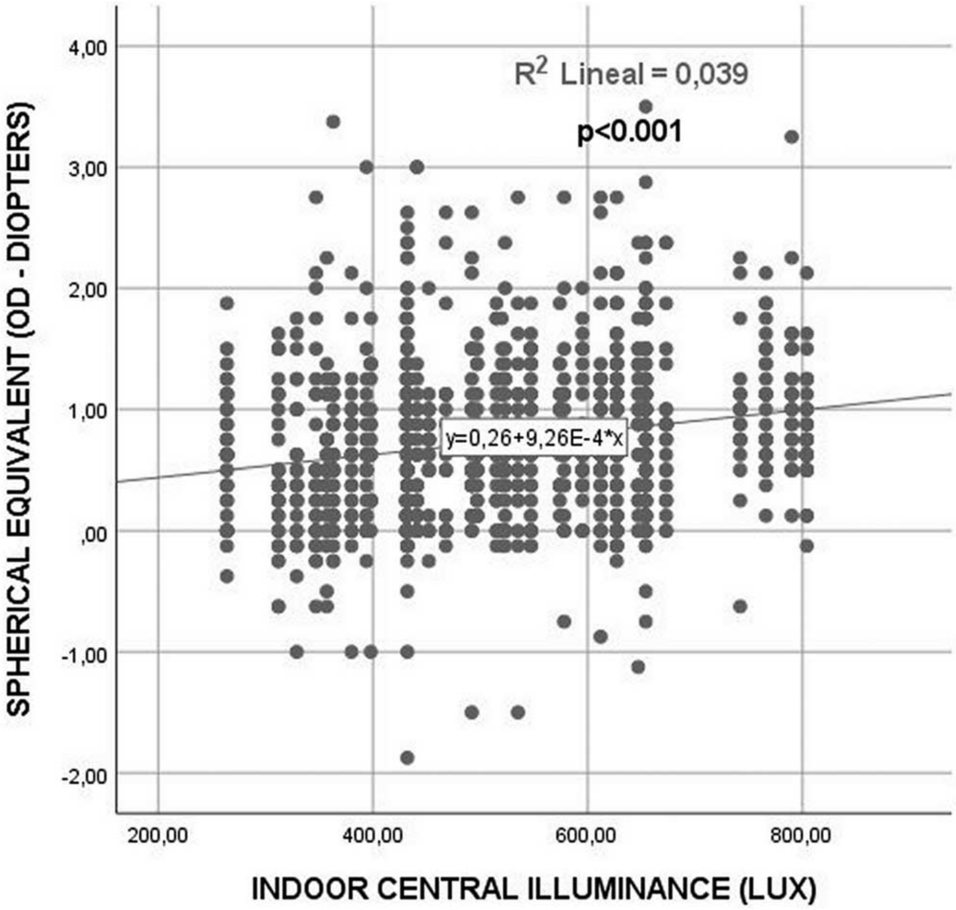

FIGURE 3. Scatterplot of the data about spherical equivalent vs central illuminance showing the positive significant correlation between refraction and illuminance.

or less in the 3 illuminance groups, where it can be seen that the low illuminance group had significantly more children in this category (chi-square $P < 0.001$).

DISCUSSION

The present study screened 4- to 5-year-old children using a PlusOptix A09 autorefractor and correlated the results with measured ambient light intensity in nursery schools. These results suggest that children attending nursery schools with brighter gathering rooms had higher mean refraction (more hyperopic reserve), and further studies are required to determine if there is a causal relationship.

The prevalence of myopia between the age of 3 to 5 years is low and increases steadily after 6 years of age in high prevalence environments. This increase has been attributed to attendance at schools with high academic load and extensive near-work demand.[17,18] However, experimental models in a variety of animals have provided evidence that myopia may develop as an adaptation to other environmental visual conditions such as circadian rhythms,[19] light intensity,[20] and light spectral composition.[21] Our present study only explored the effect of indoor illuminance on refractive error.

Table 2. Percentage of children in different refractive groups by illuminance

	n	Plano or less	+1.00 D or more
Low Illuminance	330	21.8% (19.4–24.2)	24.8% (22.3–27.3)
Median Illuminance	434	15.2% (13.1–17.3)	32.7% (30.0–35.4)
High Illuminance	367	9.0% (7.3–10.7)	42.2% (39.3–45.1)

Chi-square $P < 0.001$ (% and 95% confidence intervals)

The Shenzhen Kindergarten Eye Study reported a cycloplegic refraction of +1.49 D at the age of 3 years and +1.23 D at the age of 6 years.[22] A study of kindergarten children showed a mean cycloplegic refractive error of +1.25 D to +1.4 D at the ages of 3 to 6 years old.[23] Mutti et al have followed prospectively infants up to age 7 and have reported a mean SE of +1.23 D for children aged 4.[24] Morgan et al reviewing the Refractive Error Study in Children (RESC) data suggested that low hyperopia, and not emmetropia, was the normal endpoint of the eye growth process.[14] Thus, preschool age seems to be a protected period against myopic shifts, as the refractions are relatively stable and no definite trend in descending mean SE was observed between the ages of 3 to 6 years.[23] There is a complex match between changes in the eye's axial length growth and lens power loss, at a period of time when corneal power is relatively stable. The loss of crystalline lens power and the axial growth are balanced, maintaining mean refractive error at low hyperopic values.[23] At the age of 6, after the period of stable refraction, a dichotomy occurs. Some children persist into adult life with stable refractions of mild hyperopia, while others have unstable refractions that cross emmetropia and continue onto myopia under certain environmental pressures.

At primary school age, future myopia onset in children[25] can be predicted using a single measure of cycloplegic refractive error. The prediction starts from first grade (age 6 years), detecting children who are less hyperopic than +0.75 D, a value that is usually expected for their age.[26] More recently, the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) Study has shown that a less hyperopic or more myopic baseline refractive error in 7- to 13-year-old children, is the best single predictor of future myopia.[27] Currently, there are no similar studies performed at younger ages.

In our study of preschool-age children, the low indoor light intensity groups had a mean noncycloplegic refraction that was low, as defined by the Interventions for Controlling Myopia Onset and Progression Report as the pre-myopic cycloplegic refraction of 6 years old.[25] Moreover, the prevalence of children with mean SE of plano or less was greater in the dimmer light nursery schools. Thus, if this study is replicated and confirmed with prospective data, perhaps indoor light intensity lower than 350 lux might be a risk factor myopia development.

Daylighting, that is using natural light to illuminate buildings, has been many times considered as a crucial factor in the design of school buildings, and classrooms must have terms and conditions to support activities with visual comfort.[28] In 1914, Waldram[29] discussed the main problems in designing daylight in the classroom. At that time, schools were built with big windows to avoid many diseases like tuberculosis.[30] Regulations concerning the level of light in schools vary between countries. For example, in Indonesia, classroom lighting requirements have to meet the light intensity of 250 lux.[31] The lower limit of the Chinese standard is 300 lux and in 50% of school buildings examined, the illuminance level just reached this value.[32] In Israel, special regulations have been installed that adjust the requirements of lighting in educational institutions although there are no controls. In nursery schools, the lower limit is 300 lux, and in primary school the minimum requirement is 400 lux. Based on our findings, these regulations could be promoting the development of myopia. Moreover, in Israel, there are several buildings that use the basement floor as a classroom, using artificial light as the only source of illumination. Thus, we suggest that the standards for ambient light in school buildings should be readjusted, and higher levels of illumination >800 lux could perhaps be considered for myopia prevention, if further work demonstrates a causal relationship.

Kindergarten children in Israel stay indoors during diurnal hours at nursery schools, with mainly artificial illumination, from Sunday to Saturday 11 months a year, since age 3 onwards, and were studied by us at age 5. This is a strength of our study because we measured children after 1 to 2 years of such a sustained and controlled environmental exposure. An important limitation of the present study is that measured refractions were noncycloplegic, therefore, our results can only be cautiously compared to published cycloplegic data. Noncycloplegic autorefraction produces instrument myopia that has been clearly shown to affect mean values of spherical equivalent in hyperopic children by −0.50 D to −0.80 D.[33] Handheld autorefractors as the one used in this study have been tested in several studies against desk autorefractometers or retinoscopy, systematically finding instrument myopia without cycloplegia.[34–38] Therefore, we suggest that an autorefraction screening approach with cycloplegia would be better when replicating this study. Thus, assuming that our methods are biased by instrument myopia, the main finding of this preliminary study is related to intergroup comparisons between kindergartens with different light levels.

Another limitation of our study is that we did not collect other information about risk factors for myopia, and thus we cannot exclude that the associations we have observed are due to confounding. This possibility needs to be considered in future studies. Besides, the significant correlation between the lower hyperopic reserve and low light intensity in our study does not imply causation. A prospective longitudinal study in several kindergartens with different illumination from ages 3 to 6, with cycloplegic autorefractometry and optical biometry, should be performed for establishing causality.

Despite these limitations, our results are consistent with considerable other evidence in the literature that links light exposure to refractive development,[3,5,8,17,39] with a possible biological link between increased dopamine release by brighter light and the well-documented ability of dopamine agonists to slow axial elongation, making a direct link more plausible.[40] If future studies confirm our findings, then increasing the light intensity of classrooms in kindergartens and primary schools could have a significant role to play in controlling the prevalence of myopia. Research in this area offers a promising avenue.

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