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Elevated light levels in schools have a protective effect on myopia

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Abstract

Purpose: To determine whether elevated light levels in classrooms in rural areas can protect school-age children from myopia onset or myopia progression.
Methods: A total of 317 subjects from 1713 eligible students aged six to 14 in four schools located in northeast China participated in the study. Students received a comprehensive eye examination including cycloplegic refraction and ocular biometry, which included axial length (AL), anterior chamber depth (ACD), and corneal curvature (CC) measurement, and completed a questionnaire. The intervention arm included 178 students in two schools with rebuilt elevated lighting systems and the control arm included 139 students in which lighting systems were unchanged. Results for the two arms were compared with a Wilcoxon rank sum test, a chi-squared test or a *t*-test, as appropriate. Factors that might help explain any differences were explored with multivariate linear regression analysis.
Results: The median average illuminance of blackboards and desks and uniformity of desk lighting were significantly improved, however, the uniformity of blackboard lighting declined after intervention. At baseline, the mean refraction, AL, CC, ACD and myopia prevalence between the two arms were not significantly different. After 1 year, compared with the control arm the intervention arm had a lower incidence of new myopia onset (4% vs 10%; $p = 0.029$), a smaller decrease in refractive error among no myopic subjects (−0.25 dioptre [D] vs −0.47 D; $p = 0.001$), and shorter axial growth for both non-myopic (0.13 vs 0.18 mm; $p = 0.023$) and myopic subjects (0.20 vs 0.27 mm; $p = 0.0001$). Multivariate linear regression analysis showed the intervention program, lower hyperopic baseline refraction, lower father's education level, longer time sleeping and less time in screen-viewing activities were associated with less refractive shift in the direction of myopia in non-myopic children. For myopic subjects, myopia progression was significantly associated with family income only. The intervention program and older age had a protective effect on axial growth for both myopic and non-myopic subjects. The father's education level and sleep duration were significantly associated with axial growth in non-myopic children.
Conclusions: Elevated light levels in classrooms have a significant effect on myopia onset, decreases in refraction, and axial growth; if the findings of lighting intervention are reproduced in future studies, the ambient light levels in schools should be improved.

Introduction

The aetiology of myopia is suggested to be genetic as well as being influenced by environmental factors.[1,2] Since the 1970s, the prevalence of myopia in youth has increased dramatically worldwide, especially in Southeast and East Asian countries including China.[3,4] Although myopia prevalence in the U.S. has been estimated to be relatively lower than in other countries, such as China, the prevalence of myopia increased over 30 years from the 1970s.[5] In the UK, increasing myopia prevalence has occurred across a range of ages: i.e. from 27% to 34% in those aged 50–54 years and 16% to 32% in those aged 55–59.[6] Therefore, an increasing number of researchers have paid more attention to environmental factors such as educational pressure,[7] urbanisation,[8] acculturation,[9] ambient visual environment,[10] more near work[11] and fewer outdoor activities.[12]

Recently, a rapidly growing body of research has been published regarding the relationship between the incidence of myopia onset and spending less time outdoors.[13,14] Subsequent reports linked reductions in the incidence of myopia onset and/or progression to interventions such as a recess outside the classroom programme in Taiwan,[15] or a programme in which 45 min of daily structured time outdoors were added in Guangzhou.[16] It seems that 'outdoors' itself contributed to the protective effect rather than 'activities',[17] in that higher light levels outdoors were thought to be of a critical importance. Furthermore, experimental animal models suggested low light levels were myopigenic, and the normal refractive development of chicks in a low-intensity light group (50 lux) became less hyperopic than a medium-intensity group (500 lux). On the other hand, the chicks raised in high light levels (10 000 lux) remained more hyperopic than the medium-intensity group until the end of treatment.[18] Form-deprived or negative-lens treated eyes exposed to elevated light levels had less of a myopia shift than those exposed to standard colony lighting (about 500 lux).[19,20] These results pointed out that elevated light levels could be a protective factor for myopia and may positively affect refractive development and responses to myopigenic stimuli.

With the hypothesis that elevated light levels may be beneficial for the refractive development of children, we rebuilt the classroom lighting systems as an intervention. To the best of our knowledge, there have been few studies on interventional lighting and myopia among a human population. In a visual ergonomics intervention study in mail sorting facilities for postal workers aged 24–63 years from 2004 to 2006, illuminance and uniformity of the shelves were improved significantly after the intervention. It was found that the most pronounced decreases in eyestrain, musculoskeletal disorders, and mail sorting times were seen among younger participants of the group.[21] In our study, we compared myopia onset and progression and ocular biometric parameters between intervention and control arms. The influence of factors related to myopia onset and progression were also assessed.

Methods

Study population

The study was a prospective, school-based interventional study that abided by the tenets of the Declaration of Helsinki. Approval was obtained from the Human Research Committee of Anhui Medical University. Informed written consent was acquired from at least one of the students' parents or other legal guardians for all participants.

Four schools (one primary school and one secondary school in the intervention arm vs one primary school and one secondary school in the control arm) from a rural area in Sujiatun district Shenyang China were selected for our study. Two primary schools that were selected for a comparable academic burden and adjacent location were assigned to the intervention arm or control arm randomly. The two secondary schools were assigned similarly. Given that students of grades 6 and 9 would go to higher level schools in September of the next year, they were excluded in our study to avoid loss of follow up. Therefore, among 1907 eligible participants of 6–14 years of age, 1713 children were included and had a distance unaided visual acuity (VA) test three times at baseline, 6 months and 1 year after intervention. To reduce the burden of a complete eye examination, a stratified cluster sampling was applied to select the participants combined with the principle of voluntariness. The sampling frame was based on the enumeration of grade-specific classes within the schools, and students of 10 classes in five grades (grade 1, grade 3, grade 5, grade 7, and grade 8) who provided consent for cycloplegia were included. The present study was based on 317 students who had refraction and ocular biometric parameter data for both baseline and at 1 year, and who completed a questionnaire, comprising a 19% subsample of the 1713 participants who underwent unaided VA testing three times (after excluding five children with orthokeratology, 12 diagnosed with amblyopia or other eye diseases, 25 who dropped out of the study because they went to another school or for other reasons, and eight students who were not given cycloplegic drops because of intraocular pressures higher than 25 mmHg in one or both eyes). A flow diagram depicting subject recruitment is shown in *Figure 1*. In general, the subsample had comparable characteristics including gender (boys/girls, 152/165 vs 883/830; $\chi^2 = 1.46$, degree of freedom [df] = 1, $p = 0.24$), mean age (10.6 ± 2.4 vs 10.8 ± 2.2; $t = -1.66$, df = 4002, $p = 0.26$), and mean uncorrected VA (0.32 ± 0.31 vs 0.29 ± 0.24 logMAR,

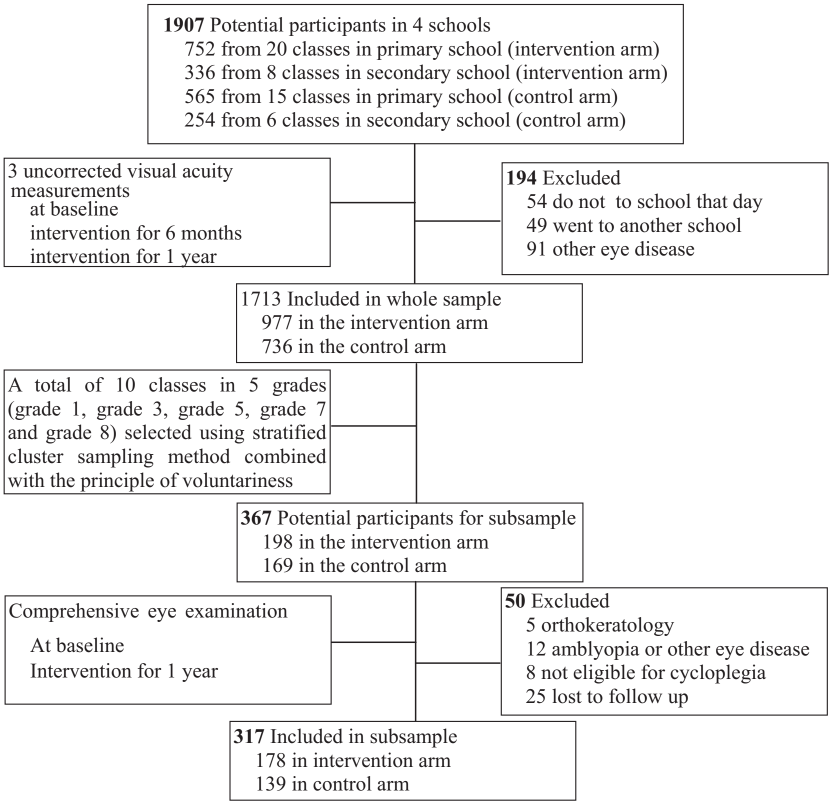

Figure 1. Flowchart detailing assignment and examination of subjects into a study of classroom lighting intervention and myopia among students in Sujiatun, China.

approximately 6/12 or 20/40 Snellen, $t = 1.11$, df = 345, $p = 0.27$) relative to the whole sample.

Interventions

Lighting systems in 56 classrooms of the intervention schools (four classes in each grade) were rebuilt in November 2012. In every classroom eight suspension-mounted grille luminaires (Philips TPS299; http://www.philips.com.cn/) with 16 fluorescent tubes (TL5-28W; http://www.philips.com.cn/) of 6500K were hung from the ceiling parallel to the window in two rows, and a separate blackboard lamp fixture (TMS122/128 EBE GDL; http://www.philips.com.cn/) with one tube (TL5-28W) was installed over the front blackboard. The blackboard luminaire was covered with a one-sided diffuser to regulate illuminance uniformity on the blackboard surface and decrease direct glare. The primary criteria were a minimum average illuminance of 300 lux on desks and 500 lux on the blackboard, uniformity levels of 0.7 and 0.8 on desks and the blackboard respectively, and a 1.7–1.9 m distance between the fluorescents lights and desk surfaces. Manual-on switches were employed to control light on/off states of the luminaires above the desks, and a separate switch was used for the blackboard lamp. All fluorescents lights were lit up when it was dim outdoors, and fluorescent lights near the interior wall were lit up on sunny days to avoid relative dimness compared to the areas beside the windows. This intervention was not implemented in the schools chosen for the control arm.

Lighting level measurements

At baseline, the illuminance of desks and blackboards of 13 classrooms (one classroom was selected from every floor of the teaching buildings randomly; seven in the intervention schools vs six in the control schools) were measured at 20:00 to 21:30 with a luxmeter (TES1330; TES Electrical Electronic Corp, http://www.tes.com.tw/). At 1 month after intervention, the light levels of 20 classrooms (all classrooms in grade 1, grade 3, grade 5, grade 7, and grade 8) from the intervention schools were measured again to estimate the new lighting levels. The illuminance (lux) of desk surfaces was measured at 48 points according to a grid distribution with measured interval of 1 m. Twenty-four points on a blackboard were measured with horizontal intervals of 0.5 m and vertical intervals of 0.4 m. Average illuminance and illuminance uniformity for desks and blackboards were evaluated at classroom light levels. The uniformity value for the illuminance was calculated as the minimum illuminance value divided by the average value.[22]

Unaided VA, refraction and ocular biometry assessment

All students took part in school-based unaided VA examinations three times at baseline, 6 months and 1 year after intervention using an E Standard Logarithm Vision Acuity Chart (VSK-VC-Y; Wehen Vision, http://www.wehenvision.com/) at a distance of 5 m. Normal uncorrected VA was defined as a VA $\leq$ 0.00 LogMAR (Snellen 6/6 or 20/20 or better).

The students of the subsample were transported to Shenyang Aier Ophthalmology Hospital for comprehensive examinations conducted by ophthalmologists and optometrists annually in 2012 and 2013. The examiners were blind to whether the students were in the intervention or control group. Examinations included an anterior segment examination with a slit-lamp biomicroscope, vitreous and fundus examinations with a direct ophthalmoscope, ocular alignment assessment with unilateral and alternating cover tests at 0.5 and 3.0 m, ocular motility assessment, intraocular pressure with a non-contact ophthalmotonometer (NT-510; Nidek, http://www.nidek-intl.com/index.html), and measurements of AL, ACD and CC by partial coherence interferometry (IOL Master; Carl Zeiss Meditex, http://www.elearning.zeiss.com/) before giving cycloplegic drops. Three biometric readings were obtained for each child with the IOLMaster and the average was used in the analysis.

Cycloplegia was then induced by instillation of six 0.5% tropicamide drops administered 5 min apart, followed by objective cycloplegic refraction not less than 20 min later determined by an initial autorefractor result which was used as a starting point for retinoscopy (YZ-24; 6 6 vision-Tech, http://www.66vision.com/). The spherical equivalent refraction (SER) calculated from the correction determined by cycloplegic retinoscopy were used in subsequent analyses.

Myopia was defined as a baseline SER of −0.50 D or less. Changes in SER, AL, CC and ACD were calculated as the values measured in 2013 minus those at baseline. Myopia progression was defined as the SER decrement in myopic children after 1 year, and myopia onset was a SER in non-myopic children that decreased to <-0.50 D.

Questionnaire

The children and their parents in the subsample who participated in the comprehensive eye examination underwent an interview using a self-administered questionnaire. Information on demographic variables, including age, sex, nationality, height and weight were collected. Parental refractive status was determined by a question for each parent: 'Is the child's father (or mother) myopic?' (Yes/No/Not sure). Parental education level categories were primary school and below, junior high school, senior high school, and college and above. Family monthly income categories were <3000 renminbi (RMB), 3000–5999 RMB, 6000–8999 RMB, and more than 9000 RMB; they were then grouped as less than 3000 RMB, 3000–5999 RMB and more than 6000 RMB for analysis because of very low numbers in the higher income group. Lifestyle-related questions were investigated as in the following example: 'In the previous week, how long did the children spend outdoors/studying (reading and writing after school)/screen-viewing activities (using TVs, computers, smart phones and other electronic devices) daily? Please check the appropriate box: less than 1, 1–1.99, 2–3.99 or 4 h or more. Additionally, how many hours did the children spend sleeping every day? (less than 7, 7–8.99, 9–10.99, or 11 h or more)'. The analysis time for such activities was in different categories due to very low numbers in some groups.

Other information, such as early life biological factors (height, weight at birth, and breastfeeding at 6 months after birth), dietary habits of the child ('how do you like sweet food? How many vegetables do you eat everyday? How much protein including milk, egg and meat do you eat everyday?') and whether the child slept with a light on or not, were also collected with the questionnaire.

Statistical analysis

Statistical software (Statistical Package for Social Science, SPSS V10.01; SPSS, China, http://www.spss.com.cn/index.aspx) was used for statistical analyses. Two-tailed p values of less than 0.05 indicated statistical significance. Participant characteristics were described as the mean and standard errors for continuous variables, numbers and proportion for categorical variables and median and interquartile ranges for levels of average illuminance and uniformity in classrooms. These variables were compared between control and intervention arms by a Student's t-tests, chi-squared tests or Wilcoxon rank sum tests as appropriate.

Analyses of SER, AL, CC, and ACD were conducted on data from the right eye only because of the high correlation between right and left eyes (SER, $r = 0.98$; AL, $r = 0.96$; CC, $r = 0.96$; ACD, $r = 0.92$). The mean SER, AL, CC, and ACD at baseline and 1 year later were calculated, and differences between the intervention and control arms were compared with a t-test. Based on the baseline and final SER, all the participants were classified into three groups: i.e. a baseline SER of −0.50 D or less was classified as the initial myopia group; a baseline SER more than −0.50 D but finial SER of −0.50 D or less was classified as the new onset myopia group; a SER more than −0.50 D both at baseline and finally was classified as the initial and final no myopia group. Prevalence in the intervention and control arms was compared with a chi-squared test. To examine the associations between changes in SER and eye axial growth and potential risk factors, a linear regression analysis was applied for myopic (baseline SER of −0.50 D or less) and non-myopic (baseline SER more than −0.50 D) students. After univariate linear analysis of potential associations, we performed a multivariate linear analysis (the backward-stepwise method was used) and changes in SER and axial elongation were taken as dependent parameters and all possible variables were taken as independent parameters, which showed a significant association with the dependent parameters in univariate analysis for myopic or non-myopic participants ($p < 0.20$). The regression coefficient (B) and the 95% confidence interval (95%CI) for B were calculated.

Results

The 1-year period of intervention was conducted from November 2012 to November 2013. The study eventually included 317 students with data from comprehensive eye examinations and a questionnaire. A total of 178 children participated in the intervention program and 139 children were included in the control arm (*Table 1*). At baseline, the intervention arm students had a comparable boy-to-girl ratio, Han-to-minority nationality ratio, primary-to-junior high school ratio as the control arm based on chi-squared test (all $p > 0.05$). Prevalence of myopia was 46% in the intervention arm vs 50% in the control arm ($\chi^2 = 0.02$, $p = 0.89$). The mean age, body mass index and unaided VA of the intervention arm and control arm at baseline were 10.7 ± 2.4 vs 10.5 ± 2.3 years ($t = 0.62$, $p = 0.54$), 19.90 ± 3.73 vs 19.74 ± 4.42 ($t = 0.34$, $p = 0.73$), and 0.33 ± 0.32 vs 0.29 ± 0.31 logMAR ($t = -1.01$, $p = 0.29$) respectively.

From 13 classrooms (seven classrooms in the intervention arm and six classrooms in the control arm), the light levels showed no statistical difference between the two arms at baseline based on Wilcoxon rank sum test. The median average illuminance (interquartile range) of desks in the intervention arm compared to the control arm was 74 lux (58–116) vs 98 lux (83–121; $p = 0.25$) and 71 lux (64–77) vs 76 lux (68–90; $p = 0.48$) for blackboards. Median uniformity of desks and blackboards was 0.55 (interquartile range 0.49–0.65) and 0.72 (interquartile range 0.62–0.75) in the intervention arm, and 0.57 (interquartile range 0.54–0.61) and 0.74 (interquartile range 0.65–0.80) in the control arm ($p = 0.67$ and $p = 0.32$), respectively. After intervention, the median average illuminance was 558 lux (interquartile range 506–603) for desks and 440 lux (interquartile range 391–506) for blackboards with the new lighting, which was improved significantly from that of desks ($p < 0.0001$) and blackboards ($p < 0.0001$) with the old lighting in the control arm (*Figure 2a*). The average illuminance of desks surpassed the recommended 300 lux. On the other hand, the average illuminance achieved only 88% of the recommended value for blackboards after intervention, where the recommended illuminance level was 500 lux. Before intervention, the uniformity of illuminance on the desks did not attain the recommended value of 0.7. The median uniformity was 0.55 (interquartile range 0.49–

Table 1. Baseline demographic characteristics and classroom lighting levels[a] in different arms

Characteristics	Intervention arm (n = 178)	Control arm (n = 139)	$\chi^2/t/Z$ value	df	p-value[b]
Boys/girls	87/91	65/74	0.14	1	0.71
Han nationality/minority nationality	164/14	123/16	1.21	1	0.27
Myopia/non-myopia	91/87	70/69	0.02	1	0.89
Mean age (S.D.) (years)	10.7 (2.4)	10.5 (2.3)	0.62	315	0.54
BMI (S.D.) (kg m^{-2})	19.9 (3.7)	19.7 (4.4)	0.34	315	0.73
Mean unaided VA (S.D.)	0.33 (0.32)	0.29 (0.31)	−1.01	315	0.29
Junior high school/primary school	83/95	64/75	0.01	1	0.92
Median average illuminance of desk (interquartile range 25–75%) (lux)	74 (58–116)	98 (83–121)	−1.14	–	0.25
Median uniformity of desk (interquartile range 25–75%)	0.55 (0.49–0.65)	0.57 (0.54–0.61)	−0.43	–	0.67
Median average illuminance of blackboard (interquartile range 25–75%) (lux)	71 (64–77)	76 (68–90)	−0.72	–	0.48
Median uniformity of blackboard (interquartile range 25–75%)	0.72 (0.62–0.75)	0.74 (0.65–0.80)	−1.0	–	0.32

S.D., standard deviation; BMI, body mass index.

[a]Thirteen classrooms in schools, seven in the intervention arm and six in the control arm.

[b]Differences between two arms, based on the chi-squared test, t-test or Wilcoxon rank sum test, as appropriate.

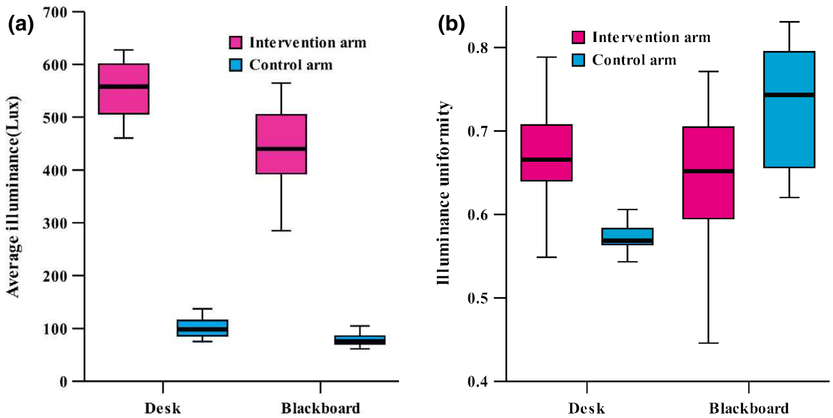

Figure 2. Boxplots showing light levels for the new lighting in the intervention arm and that in the control arm. (a) Average illuminance of desks and blackboards in the two arms. (b) uniformity of desks and blackboards in the two arms. After intervention, the average illuminance of desks, the average illuminance of blackboards and uniformity of desks were significantly higher than the control arm, but the uniformity of blackboards decreased. The upper and lower hinges of the box indicate the 75th and the 25th percentiles of the data set, separately; whiskers extend to a maximum of 1.5 times the interquartile range.

0.65), but it increased to 0.67 (interquartile range 0.64–0.71) after intervention nearly reaching the recommended value, which was significantly higher than the control arm ($p < 0.0001$). However, the uniformity of illuminance of the blackboards declined to 0.65 (interquartile range 0.59–0.71), which was significantly lower than the control arm, because only one light fixture was added to just one half of the blackboard as the other half was used for multi-media presentations ($p = 0.045$; *Figure 2b*).

The mean refraction, AL, CC, and ACD at baseline and the final point and the mean changes during the follow-up period of the two arms were compared with a *t*-test, as shown in *Table 2*. The mean SER, AL, CC and ACD of participants in the intervention arm at baseline and final point were not significantly different from the control arm, except for the final mean SER in non-myopia children (0.33 ± 0.50 vs 0.13 ± 0.61 D; $t = 2.19$, df = 154, $p = 0.03$). Compared with the control arm, the intervention arm showed a smaller decrease in refraction (−0.25 ± 0.40 vs −0.47 ± 0.40 D; $t = 3.39$, df = 154, $p = 0.001$) and axial elongation (0.13 ± 0.17 vs 0.18 ± 0.12 mm; $t = -2.3$, df = 154, $p = 0.023$). Among

Table 2. Spherical equivalent refraction, axial eye length, corneal power and anterior chamber depth at initial and final visits and changes in different arms

	Initial values		Final values		Changes	
	Intervention arm	Control arm	Intervention arm	Control arm	Intervention arm	Control arm
Non-myopic Children[a]						
Refraction (D)	0.58 ± 0.46	0.59 ± 0.53	0.33 ± 0.50*	0.13 ± 0.61*	−0.25 ± 0.40**	−0.47 ± 0.40**
Axial length (mm)	23.10 ± 0.63	23.06 ± 0.68	23.23 ± 0.66	23.23 ± 0.70	0.13 ± 0.17*	0.18 ± 0.12*
Corneal power (D)	43.06 ± 1.19	43.18 ± 1.40	43.12 ± 1.14	43.23 ± 1.48	0.06 ± 0.20	0.06 ± 0.41
Anterior chamber depth (mm)	3.44 ± 0.24	3.42 ± 0.23	3.49 ± 0.23	3.45 ± 0.24	0.05 ± 0.12	0.04 ± 0.09
Myopic Children[b]						
Refraction (D)	−2.28 ± 1.40	−2.23 ± 1.35	−2.52 ± 1.42	−2.54 ± 1.47	−0.25 ± 0.47	−0.31 ± 0.46
Axial length (mm)	24.37 ± 0.76	24.19 ± 0.78	24.60 ± 0.76	24.46 ± 0.80	0.20 ± 0.11**	0.27 ± 0.10**
Corneal power (D)	43.48 ± 1.33	43.70 ± 1.41	43.60 ± 1.31	43.83 ± 1.39	0.12 ± 0.18	0.13 ± 0.30
Anterior chamber depth (mm)	3.69 ± 0.23	3.63 ± 0.21	3.73 ± 0.24	3.67 ± 0.21	0.04 ± 0.17	0.04 ± 0.07

*Compared with the control arm $p < 0.05$; **compared with the control arm $p < 0.01$.

D, dioptre.

[a]156 Non-myopia children at baseline, 87 in the intervention arm vs 69 in the control arm.

[b]161 Myopia children at baseline, 91 in the intervention arm vs 70 in the control arm.

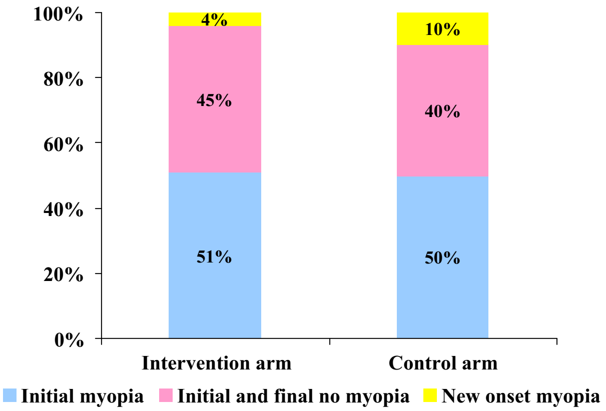

Figure 3. Bar graph showing the prevalence of new onset myopia of the two arms in the follow-up. The prevalence of new onset myopia was significantly lower in the intervention arm than in the control arm.

myopic children, the mean axial elongation was significantly shorter in the intervention arm than in the control arm (0.20 ± 0.11 vs 0.27 ± 0.10 mm; $t = -4.13$, df = 159, $p = 0.0001$). Myopia progression was not significantly different in the two arms (−0.25 ± 0.47 vs −0.31 ± 0.46 D; $t = 0.86$, df = 159, $p = 0.39$). There were no significant differences in changes in CC and ACD between the two arms. In addition, we found the prevalence of new onset myopia was significantly lower in the intervention arm than in the control arm (4% vs 10%; $\chi^2 = 4.76$, df = 1, $p = 0.029$; *Figure 3*).

In univariate analysis, greater changes in SER were associated with non-participation in the intervention program, more hyperopic SER, less sleep time, and more time for studying and screen-viewing activities in non-myopic students. Among myopic participants, greater decreases in SER occurred in students with shorter eyes and higher family incomes and students who spent more time studying after school. In multivariate models, greater changes in SER for non-myopic subjects were associated with non-participation in the intervention (0.24 D, 95%CI: 0.12–0.37; $p = 0.0001$), more hyperopic baseline refraction (−0.21 D, 95%CI: −0.33 to −0.09; $p = 0.001$), father with a higher level of education (−0.08 D, 95%CI: −0.17 to −0.003; $p = 0.048$), less time spent sleeping (0.11 D, 95%CI: 0.005–0.21; $p = 0.039$) and more time spent on screen-viewing activities such as focussing eyes on the screens of a TV, computer, mobile phone, and other electric devices (−0.13 D, 95%CI: −0.27 to −0.04; $p = 0.047$). Time spent studying after school was not included in the multivariate model. Among the myopic subjects, those who had lower family incomes suffered from a greater shift in refraction error than those with higher family incomes (0.16 D, 95% CI: 0.05–0.27; $p = 0.004$) (*Table 3*). Factors found to be associated with axial elongation in univariate analysis were the intervention program and older age among all participants, but higher family income was associated only with myopic children. Multivariate analysis of axial growth indicated that, compared with participants in the control arm, those in the intervention arm were significantly more likely to have less elongation for either non-myopic (−0.06 mm, 95%CI: −0.11 to −0.01; $p = 0.006$) or myopic children (−0.07 mm, 95%CI: −0.10 to −0.04; $p < 0.0001$). Furthermore, each additional year of age was associated with 0.02 mm less axial elongation in both non-myopic ($p = 0.0002$) and myopic participants ($p = 0.01$). However, greater axial growth among non-myopic students was significantly associated with fathers having lower levels of education (0.03 mm, 95%CI: 0.001–0.06; $p = 0.032$) and longer sleeping times (−0.05 mm, 95%CI: −0.09 to −0.02; $p = 0.006$) (*Table 4*).

Discussion

This study was the first prospective, interventional study to investigate the relationship between elevated light levels in classrooms and myopia onset and progression among primary and junior high school students in the Northeast China. We evaluated the changes in SER and AL. Based on numerous epidemiological studies that reported a protective effect on myopia among children[7,15] with more time outdoors and animal models that showed brighter light levels arrested normal decreases in hyperopia during refraction development[19] and slowed the rate of myopia development for both lens-induced and form-deprivation myopia in tree shrews[23], the hypothesis that higher levels of light could be protective for myopia onset and progression in children has been promoted.[24] However, there have been few interventional studies on myopia in students via enhancing ambient light illuminance in schools. We found that children who studied with higher ambient light levels in school had both a smaller decrease in refraction, especially for non-myopic children and a smaller increase in AL among all participants compared to controls. These data on myopia development were comparable to those obtained in a ‘recess outside the classroom’ intervention study by Wu *et al.*[15] who demonstrated a mean myopia shift of −0.25 ± 0.68 D $year^{-1}$ for the ROC group and −0.38 ± 0.69 D $year^{-1}$ for the control group. These results suggested that the lighting intervention programme had a protective effect on refractive error change and axial elongation in children.

Before intervention in this study, the classrooms were lit by six or fewer naked fluorescent lamps and in all classrooms, the mean illuminance of desks and blackboards was below the required values of 300 and 500 lux, respectively. The levels of uniformity in illumination of desks and blackboards in most classrooms were also below the required values of 0.7 and 0.8, respectively. The poor lighting condi-

Table 3. Parameters associated with changes in SER within 1 year in myopic and non-myopic children

Parameters	Non-myopic children (n = 156)		Myopic children (n = 161)	
	B (95%CI) in univariate regression[a]	*B* (95%CI) in multivariable regression[b]	*B* (95%CI) in univariate regression[a]	*B* (95%CI) in multivariable regression[b]
Intervention program	0.22 (0.09, 0.34)**	0.24 (0.12, 0.37)**	0.06 (−0.08, 0.21)	–
Baseline SER (D)	−0.21 (−0.34, −0.08)**	−0.21 (−0.33, −0.09)**	−0.008 (−0.06, 0.05)	–
Age (years)	−0.001 (−0.03, 0.03)	–	−0.005 (−0.05, 0.04)	–
Level of education, father	−0.04 (−0.13, 0.05)	−0.08 (−0.17, −0.003)*	−0.05 (−0.16, 0.06)	–
Level of Education, mother	−0.03 (−0.11, 0.06)	–	0.02 (−0.10, 0.14)	–
Parental myopia	0.03 (−0.12, 0.17)	–	0.05 (−0.12, 0.21)	–
Family income (RMB monthly)	0.04 (−0.06, 0.14)	–	0.14 (0.04, 0.25)**	0.16 (0.05, 0.27)**
Sleeping duration (hours daily)	0.03 (−0.07, 0.14)*	0.11 (0.005, 0.21)*	0.01 (−0.12, 0.14)	–
Time spent studying after school (hours daily)	−0.02 (−0.15, 0.11)*	–	−0.12 (−0.25, 0.04)*	–
Time spent on screen-viewing activities (hours daily)	−0.07 (−0.22, 0.07)*	−0.13 (−0.27, −0.04)*	0.003 (−0.14, 0.15)	–
Time Outdoors (hours daily)	−0.03 (−0.16, 0.10)	–	−0.05 (−0.21, 0.11)	–

B, regression coefficient; 95%CI, 95% confidence interval; SER, spherical equivalent refraction; RMB, Renminbi.
The categorical variables (coded by 1–4) include gender (1 = boys, 2 = girls); nationality (1 = Han, 2 = minority); intervention program (1 = no, 2 = yes); education levels of parents (1 = primary school and below, 2 = junior high school, 3 = senior high school, 4 = college degree and above); parental myopia (1 = none, 2 = either or both); family income (1 = less than 3000, 2 = 3000–5999, 3 = more than 6000); sleep duration (1 = less than 7, 2 = 7–9, 3 = more than 9) and time spent studying, screen-viewing activities, and outdoors (1 = less than 2, 2 = 2 h or more).
[a]Listed all the variables associated with changes in SER or axial elongation in univariate regression ($p < 0.2$).
[b]Method of backward selection was applied, and adjusted for gender, nationality and body mass index.
*$p < 0.05$; **$p < 0.01$.

Table 4. Parameters associated with axial elongation within 1 year in myopic and non-myopic children

Parameters	Non-myopic children (n = 156)		Myopic children (n = 161)	
	B (95%CI) in univariate regression[a]	*B* (95%CI) in multivariable regression[b]	*B* (95%CI) in univariate regression[a]	*B* (95%CI) in multivariable regression[b]
Intervention program	−0.06 (−0.10, −0.008)*	−0.07 (−0.11, −0.02)**	−0.07 (−0.10, −0.04)**	−0.07 (−0.10, −0.03)**
Baseline SER (D)	−0.003 (−0.05, 0.05)	–	−0.003 (−0.02, 0.01)	–
Age (years)	−0.02 (−0.03, −0.01)**	−0.02 (−0.03, −0.01)**	−0.02 (−0.03, −0.006)**	−0.02 (−0.02, −0.006)**
Level of education, father	0.03 (−0.005, 0.06)	0.03 (0.001, 0.06)*	0.009 (−0.02, 0.04)	–
Level of education, mother	0.02 (−0.02, 0.05)	–	0.008 (−0.02, 0.04)	–
Parental myopia	−0.03 (−0.08, 0.02)	–	0.03 (−0.01, 0.06)	–
Family income (RMB monthly)	−0.007 (−0.04, 0.03)	–	−0.03 (−0.06, −0.003)*	–
Sleeping duration (hours daily)	−0.03 (−0.07, 0.009)	−0.05 (−0.09, −0.02)**	0.01 (−0.02, 0.04)	–
Time spent studying after school (hours daily)	0.02 (−0.03, 0.07)	–	−0.003 (−0.04, 0.03)	–
Time spent on screen-viewing activities (hours daily)	−0.02 (−0.08, 0.03)	–	−0.009 (−0.04, 0.03)	–
Time outdoors (hours daily)	0.003 (−0.04, 0.05)	–	−0.01 (−0.05, 0.03)	–

B, regression coefficient; 95%CI, 95% confidence interval; SER, spherical equivalent refraction; RMB, Renminbi.
The categorical variables (coded by 1–4) include gender (1 = boys, 2 = girls); nationality (1 = Han, 2 = minority); intervention program (1 = no, 2 = yes); education levels of parents (1 = primary school and below, 2 = junior high school, 3 = senior high school, 4 = college degree and above); parental myopia (1 = none, 2 = either or both); family income (1 = less than 3000, 2 = 3000–5999, 3 = more than 6000); sleep duration (1 = less than 7, 2 = 7–9, 3 = more than 9) and time spent studying, screen-viewing activities, and outdoors (1 = less than 2, 2 = 2 h or more).
[a]Listed all the variables associated with change in SER or axial elongation in univariate regression ($p < 0.2$).
[b]Method of backward selection was applied, and adjusted for gender, nationality and body mass index.
*$p < 0.05$; **$p < 0.01$.

tions in Sujiatun schools were comparable with those in an Italian school.[25] After intervention, the average illuminance and uniformity of desks were significantly improved with a median average illuminance of desks up to 558 lux (interquartile range 506–603), which surpassed the recommended 300 lux produced by applying an increased quantity and better quality of T5 fluorescent lamps, and the median uniformity increased to 0.67 (interquartile range 0.64–0.71) approaching the recommended value of 0.7 due to the wide distribution and white louvres of the suspended luminaires. On the other hand, the lighting condition of blackboards was not improved as much as expected because only one blackboard lamp fixture was mounted in front of half of the blackboard because the other side was occupied by multimedia presentations. The median average illuminance increased to 88% of the recommended 500 lux and uniformity declined to 0.65 (interquartile range 0.59–0.71) from a pre-intervention value of 0.72 (interquartile range 0.62–0.75). Previous studies showed that lighting intervention could affect humans, not only regarding vision, but in other aspects, such as alertness, vitality, performance, and even diurnal rhythms. Smolders and coworkers[26] tested the effects of two illuminance levels (200 lux or 1000 lux at eye level, 4000K) during 1 h of daytime exposure with 32 students. They found that participants felt less sleepy and more energetic in the high vs low lighting condition, had shorter reaction times on a psychomotor vigilance task and increased physiological arousal. A pilot study[27] on variable lighting, that is, variable in illuminance and color temperature during a 9 month period, found that students in the intervention group made fewer errors, particularly fewer errors of omission under the 'concentrate' program (1060 lux, 5800K), and reading speed rose significantly faster than students in the control group (300 lux, 4000K).

Findings from a previous study suggested that the age of myopia onset may become increasingly younger in most areas of the world. In Southeast Asia the peak age of myopia onset is 12–13 years,[4] however, the prevalence of myopia in the UK is at a relatively low level of 18% for a similar age[28] despite myopic children been only 14% of a cohort born between 1920 and 1990.[6] The data of National Health and Nutrition Examination Survey (NHANES) showed that more children of school age in the US were identified as having myopia.[5] Our results demonstrated that the incidence of myopia onset declined with exposure to higher classroom light levels during the daytime. Higher ambient light levels reduced the impact of myopiagenic stimuli (e.g. more time reading and writing in classrooms). Feldkaemper *et al.*[29] found that the eyes of chicks became more sensitive to image degradation at low light levels (5.5 lux) and suggested that human eyes may be more prone to developing myopia if the light levels were low during extended periods of near work.

We found that more time sleeping at night had a positive effect on decreasing SER as well as axial growth among non-myopic children. Decreased sleeping duration means more time exposed to electric light at night which may affect diurnal cycles by the suppression of melatonin.[30] Many ocular processes showed diurnal fluctuations under various levels of ambient illumination encountered over the 24 h diurnal cycle of light and dark.[31] Experimentally, exposing chickens to constant light or darkness to disturb the diurnal cycle caused excessive eye growth and corneal flattening.[32,33] More than 10 years ago, a strong relation was demonstrated between the absence of a daily period of darkness in the first 2 years after birth and the prevalence of myopia during childhood,[34] and a strong relation between myopia progression in young adults and less daily exposure to darkness was reported among Caucasians.[35] On the contrary, the associations were not found in the populations of the UK[36] and Singapore.[37]

In this study, near work, including activities of studying (after school) and screen-viewing using computers, TVs, smart phones and so on were surveyed, and a negative effect on myopia progression was found only for screen-viewing activities. Various types of near work were also measured and significant relations with myopia were reported by Zhang *et al.*[38] and Lee *et al.*[8] Lee *et al.* suggested that each activity may affect myopia in a unique way and the mechanisms may be different.

Recently, researchers have paid more attention to the potential influence of urbanisation on myopia, and the possible adverse effects of higher urbanisation levels have been verified.[8,39] Family income may be a factor that reflects urbanisation levels to some extent, and the influences on myopia are complicated by the effects of housing type, lighting levels, parental education levels, and parental myopia. A weak statistical association between family income and myopia or high myopia was detected in Chinese children[40] but not in Singaporean children.[41] The Guangzhou survey reported that families with myopic parents tended to have higher incomes.[40] Inconsistent with previous studies, we found that children from families with higher incomes had smaller myopia shifts, and the association between myopia progression and parental myopia was not significant. A possible explanation is the small sample size used in the study. As reported by Xiang *et al.*[40] the mean SER generally became more myopic in the children whose parents had secondary and tertiary education. In our study, higher levels of the father's education were a risk factor for decreases in SER and axial elongation among non-myopic children. Parents with higher education levels had a greater likelihood to be myopic and spend more time on near work or being indoors. The shared family environment has often been assumed to be the crucial reason for family clustering of myopia.

In our study, axial elongation among students in the intervention arm was retarded by improving the ambient illuminance in the daytime, which was consistent with changes in SER and with older age, and was associated similarly with less axial growth. The results were comparable to the detailed analysis by Xiang *et al.,*[42] which showed longitudinal shifts in refraction and ocular components among Chinese children. Their analysis showed annual changes in SER and AL in younger children (aged 7–11) were larger than in older children (aged 12–15), and axial elongation and myopia progression were accelerated before myopia onset and decreased after myopic refraction was established. The Correction of Myopia Evaluation Trial (COMET) study group estimated 15.61 years old to be the age of myopia at stabilisation in an ethnically diverse cohort.[43] The participants recruited in our study were younger than the estimated age and that may be one reason for the effective intervention results.

Strengths of our study include taking effective light intervention into primary and secondary schools, detailed measurement of refraction and ocular biometry, and assessment of various potential risk factors. Limitations of the study should be mentioned. First, the students who were willing to travel to the hospital for an eye examination were too few, therefore, there was a lack of individual randomisation and the possibility of selection bias. Second, the subjects were from rural areas only, so the results cannot be extended to a population settled in an urban area. Third, our intervention program was not perfect regarding the illuminance and uniformity of blackboards.

In summary, our study revealed that higher ambient light levels in classrooms protected non-myopic students from myopia onset and decreases in SER, and retarded axial growth for both myopic and non-myopic students. Going outdoors and playing is suggested to be an important method for myopia prevention and progression. We suggest that higher indoor ambient light levels are another conceivable and simple protective intervention. However, it is worth noting that exposing oneself to electrical lighting in the late evening influences circadian rhythms by disrupting melatonin signalling, which may potentially impact health and function. Future studies are needed to explore the range of light levels that are most protective of vision in children.

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