· Investigation ·

Effect of artificial natural light on the development of myopia among primary school-age children in China: a three-year longitudinal study

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Abstract

● **AIM:** To assess the efficacy of artificial natural light in preventing incident myopia in primary school-age children.

● **METHODS:** This is a prospective, randomized control, intervention study. A total of 1840 students from 39 classes in 4 primary schools in Foshan participated in this study. The whole randomization method was adopted to include classes as a group according to 1:1 randomized control. Classrooms in the control group were illuminated by usual light, and classrooms in the intervention group were illuminated by artificial natural light. All students received uncorrected visual acuity and best-corrected visual acuity measurement, non-cycloplegic autorefraction, ocular biometric examination, slit lamp and strabismus examination. Three-year follow-up, the students underwent same procedures. Myopia was defined as spherical equivalent refraction ≤ -0.50 D and uncorrected visual acuity <20/20.

● **RESULTS:** There were 894 students in the control group and 946 students in the intervention group with a mean±SD age of 7.50±0.53y. The three-year cumulative incidence rate of myopia was 26.4% (207 incident cases among 784 eligible participants at baseline) in the control group and 21.2% (164 incident cases among 774 eligible participants at baseline) in the intervention group [difference of 5.2% (95%CI, 3.7% to 10.1%); *P*=0.035]. There was also a significant difference in the three-year change in spherical equivalent refraction for the control group (-0.81 D) compared with the intervention group [-0.63 D; difference of 0.18 D (95%CI, 0.08 to 0.28 D); *P*<0.001]. Elongation of axial length was significantly different between in the control group (0.77 mm) and the intervention group [0.72 mm; difference of 0.05 mm (95%CI, 0.01 to 0.09 mm); *P*=0.003].

● **CONCLUSION:** Artificial natural light in the classroom of primary schools can result in reducing incidence rate of myopia during a period of three years.

● **KEYWORDS:** myopia; artificial natural light; school-age children; efficacy

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INTRODUCTION

Myopia is the most common ocular disorder worldwide with increasing prevalence over the past decades, especially in the East Asian populations[1-3]. In China, the 3-year incidence of myopia [spherical equivalent refraction (SER) ≤-0.5 D] in school-aged children aged 6-7y was 39.5%[4]. In urban areas, such as Guangzhou, the prevalence of myopia was 30.1% in 10 years old and up to 78.4% in 15 years old, respectively[5]. It has been estimated that myopia will affect nearly half of the world population by 2050 and become a major public health challenge[6-7].

Although most people with myopia have normal visual acuity when appropriately corrected, myopia is a risk factor for myopic maculopathy, retinal detachment, subretinal neovascularization, cataract and glaucoma in adult life, and the risk increases with the degree of myopia[8-10]. All these conditions are more challenging to treat than myopia itself. Since myopia progression is rapid during school-age years, it is very important to prevent or slow the progression and reduce the risk of pathologic myopia; therefore, finding methods to reduce progression of myopia is becoming increasingly important.

Recently, evidence has been shown that children who spend more time outdoors have a lower incidence of myopia[4,11]. Meta-analysis assessed the benefit of outdoor activities on myopia concluded the mean difference in rate of myopic shift between the intervention and control groups ranged from 0.06 to 0.23 D per year with an overall difference of 0.13 D per year, though the exact mechanism is still unknown[12]. A significant difference between outdoor and indoor environment is light. Artificial light in door is quite different from natural light in terms of rhythm, illuminance, stroboscopic and spectrum[13]. A study suggested that myopic prevalence may be related to the emergence of artificial light[14]. The Guangzhou Outdoor Activity Longitudinal Trial showed that the addition of 40min of outdoor activity can reduce myopia incidence rate over the next three years[4]. It is believed to be probably due to light spectrum difference between indoor and outdoor[15-16].

One of our research team members, Engineer Wu YL, synthesized artificial natural light (ANL) with optical cryptography technology that is similar of the natural spectrum of outdoor light. The purpose of this investigation was to evaluate the efficacy of ANL in reducing the incidence rate of myopia in Chinese children.

SUBJECTS AND METHODS

Ethical Approval Ethics approval was obtained from the Institutional Review Board of Foshan Second Hospital (KJ2019063). This study conducted between September 2020 and March 2023. This study met the Declaration of Helsinki's tenets and was registered on the Chinese Clinical Trial Registry (identifier: ChiCTR2000038078). Informed consent was obtained from a parent or legal guardian before starting the study.

Study Design and Grouping In this prospective, randomized control, intervention study, a cluster sampling method was utilized. Literature indicated that the prevalence of myopia in Chinese children aged 7-9y was 8.4%[17]. According to the sample size calculation formula of the sampling survey rate,

$$n=\left(\frac{Z_{1-\alpha/2}}{\delta}\right)^2$$

the margin of error is specified as 2%, the sample size was calculated to be 739 at 95% confidence level. For this study a design effect of 2 was assumed, therefore a minimum of 1478 individuals were required along with 1846 individuals to allow the 20% dropout rate.

Following the overall randomization method, 4 public primary schools with grade 2 and 3 students in Foshan City were included in this study, and the classes were taken as groups according to 1:1 randomized control. Ten classes participated from each of the three schools and 9 classes participated from one school, making it a total of 39 classes and 1840 students. There were 19 classes and 894 students in the control group, and 20 classes and 946 students in the intervention group.

Data at baseline were gathered on children in grade 2 and grade 3 (age: 7-9y), with annual follow-up to grade 4 and grade 5. Students in primary schools in China generally do not change schools.

Exclusion criteria included a history of eye surgery, amblyopia, strabismus, systemic or ocular pathologies.

Research Methods Based on the information of the students provided by each school, the students were numbered and barcodes were produced. All the barcodes included subject numbers and school and student names to make verification easy. The medical history of all students was recorded and uncorrected visual acuity, best corrected visual acuity (BCVA), autorefraction, ocular biometry, slit-lamp examination, binocular strabismus examination, and fundus examination were also performed. Students with a history of ophthalmic surgery were not included in this study. The data of uncorrected visual acuity, BCVA, strabismus, and slit lamp examination were manually entered into the electronic data capture (EDC) (https://main.solomonedc.com/projects), whereas the data from the IOL Master and autorefractor were uploaded automatically to the EDC through the network. The height, weight, and myopia status of students' parents were investigated by questionnaire.

Measurements The ophthalmic examinations were performed at school by 1 ophthalmologist, 1 senior optometrist, 2 ophthalmic nurses and 4 medical students. Field work was preceded by training sessions and pilot exercises at 1 primary school. The examination protocols were based on protocols used in Refractive Error Study in Children[18].

Vision acuity of both eyes was assessed by following standard procedures using tumbling E ETDRS charts (Guangzhou Xieyi Weishi Medical Technology Co., LTD., www.wehenvision.com). BCVA was measured when uncorrected visual acuity was <20/20. Cover and uncover tests were used to identify tropia at both near and distance.

Non-cycloplegic refraction (NCR) was performed in this study. Autorefraction using the Topcon KR 800 was performed, with 3 measurements taken on the right eye and 3 on the left eye. The mean value of 3 valid measurements was calculated. Follow-up examinations (during 2021-2023) were the same as the baseline in 2020 and conducted by the same examiners and using the same equipment. The baseline and follow-up examination in 2021 were performed during the same time of year (October to November), the follow-up examination in 2023 were performed in March because of COVID-19 pandemic in November in 2022. The data autorefractor were uploaded automatically to the EDC through the network in real-time.

Axial length (AL), anterior chamber depth (ACD), and corneal curvature (CC) were measured by noncontact partial-coherence laser interferometry using the IOL Master (Carl Zeiss Meditec). The test was repeated 5 times and averaged before being uploaded to the EDC. The measures were taken for the right eye only.

Information on risk factors for myopia, including parents' education level, myopic status, child's daily activities, were collected using questionnaire. The questionnaire also included student's height, weight, birth condition, eating habits, *etc*.

Quality Control Visual acuity measurements were performed by trained medical students. The autorefraction and IOL Master were performed by specially trained ophthalmic technicians, Yuetong Yan and Chen YS, respectively. Slit-lamp examination, strabismus examination, and fundus examination were performed by Xian BK. Manually recorded data of visual acuity, strabismus, and slit lamp examination were entered and verified by Chen YS. All data were collected at the students' schools to increase the participation rate.

Methods of Intervention The control group was exposed to the usual classroom lighting system while the intervention classrooms were exposed to ANL (Figure 1; Guangdong Cosio Lighting Co. ltd, http://www.cosiolighting.com/). The number, layout, and height of lights in the intervention and control classrooms were the same and each classroom had nine sets of lamps. The light source switches of all classes were transformed and connected to the network, and the use of lamps could be monitored in real-time through self-developed application. A spectral measurement instrument (Model OSP-350S, Hangzhou Ouhong INTELLIGENT Technology Co. Ltd, http://www.ohomesmart.com/) measured the spectral and lighting parameters of the classroom light source (Figures 2 and 3; Table 1). The spectrogram of the light source in the intervention classroom has a slightly different shape than the spectrogram of the light source in the control classroom. The spectrogram of the light source in the intervention classroom has a peak at around 530 nm, which corresponds to the green color. The spectrogram of the light source in the control classroom has a peak at around 580 nm, which corresponds to the yellow color. Overall, the spectrogram of the light source in the intervention classroom suggests that it is more blue-shifted (shorter wavelength) light source than the light source in the control classroom.

Definition of Myopia Due to large number of participants, to avoid the influence of mydriasis on children and to improve the student's compliance to participate in the study, NCR was performed in this study. Myopia was defined as SER≤-0.50 D and uncorrected visual acuity <20/20 according to the NCR combined with uncorrected visual acuity. This definition was chosen base on previous epidemiological investigation[2,19].

Figure 1 Intervention classroom with ANL ANL: Artificial natural light.

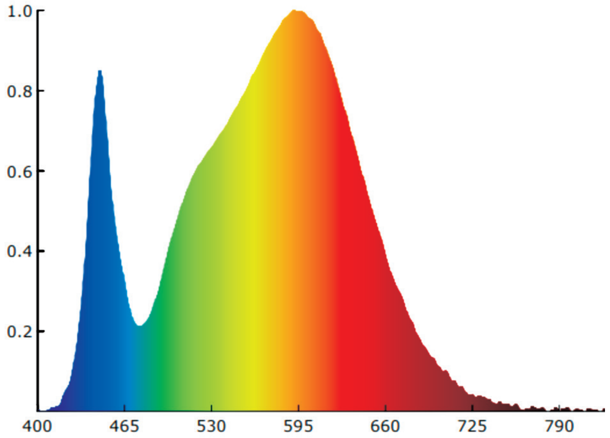

Figure 2 Spectrogram of the light source in the control classroom.

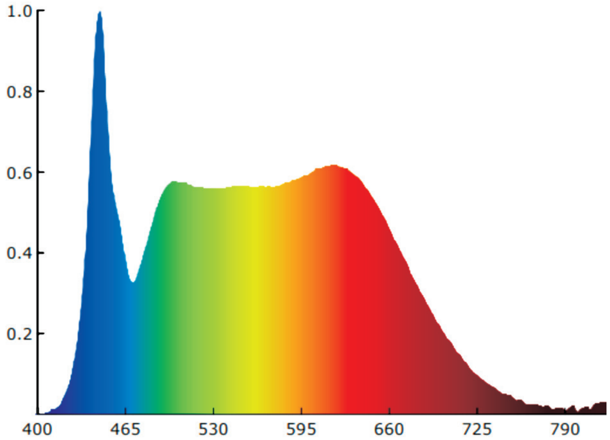

Figure 3 Spectrogram of the light source in the intervention classroom.

Statistical Analysis The data of this project were all exported from the EDC. STATA 17.0 was used for data cleaning and statistical analysis. SER=sphere+1/2cylinder. Due to the good correlation between binocular data, the right eye data were used for statistical analysis. The descriptive statistical parameters and their statistical symbols are as follows. Normal measurement: mean±standard deviation; non-normal measurements: mean rank sum, and counts frequency or constituent ratio. If the two groups of data obey normal distribution, the independent sample *t*-test was performed, followed by the *F* test of homogeneity of variance. The *t*-test

Table 1 Comparison of class light parameters between the control group and the intervention group mean±SD

Parameters	Control group	Intervention group	*t*	*P*
Class, No.	19	20		
Illumination, lx	490.76±28.21	511.83±49.75	-1.65	0.143
Color temperature	3850.74±125.47	5020.40±134.10	-28.09	<0.001
CRI	82.87±1.05	98.18±0.48	-58.90	<0.001
Red light CRI	9.21±4.78	92.70±1.45	-74.62	<0.001

CRI: Color rendering index.

Table 2 Comparison of demographic biological characteristics, SER, and ocular biometric parameters between the control group and the intervention group

Parameters	Control group (n=875)[a]	Intervention group (n=931)[a]	t/χ^2	*P*
Age (y)	7.59±0.53	7.41±0.54	7.017	0.001
Male (%)	460 (52.57)	507 (54.46)	0.645	0.422
Height (m)	1.31±0.07	1.31±0.07	1.453	0.146
Body weight (kg)	28.52±7.21	27.94±6.84	1.434	0.152
Body mass index[b]	16.43±3.55	16.29±3.57	0.6544	0.513
Wearing glasses (%)	85 (14.3)	98 (14.5)	0.014	0.906
Uncorrected visual acuity	0.86±0.24	0.88±0.22	-1.567	0.117
Spherical equivalent refraction (D)	-0.34±1.07	-0.39±1.01	1.113	0.256
Prevalence of myopia (%)	73/875 (8.5)	87/861 (10.1)	0.1256	0.723
Axial length (mm)	23.08±0.83	23.09±0.81	-0.2568	0.797
Corneal curvature (D)	43.27±1.44	43.22±1.44	0.691	0.488
White to white distance (mm)	12.19±0.39	12.20±0.38	-0.895	0.371
Anterior chamber depth (mm)	3.38±0.24	3.37±0.36	0.902	0.377
Outdoor time per day (%)				
<2h	508 (85.4)	598 (88.6)	2.906	0.088
>2h	87 (14.6)	77 (11.4)		
Parental myopia (%)				
No	143 (24.2)	184 (27.7)	2.432	0.296
Father or mother	254 (43.1)	262 (39.4)		
Father and mother	193 (32.7)	219 (32.9)		

[a]Right eye data for students who completed baseline examination. [b]Calculalted as weight in kilograms divided by height in meters squared. SER: Spherical equivalent refraction.

was used if the variance was homogeneous, and the *t*-test was used if the variance was not homogeneous. Mann-Whitney *U* test was used to compare non-normal data between the two groups. The Chi-square test was performed to compare the intergroup count data.

RESULTS

The control group in this study included 19 classes with a total of 894 students. At baseline examination in 2020, a total of 4 students in the control group had strabismus, 4 amblyopia, and 11 had eye surgery, therefore these were not included in the data analysis. The intervention group consisted of 20 classes with a total of 946 students, at baseline examination, 5 students with strabismus, 2 amblyopia, and 8 with eye surgery were not included in this investigation. During the third year of follow-up in 2023, 35 students were lost to follow-up due to transfer in intervention group and 16 students in control group (Figure 4).

The characteristics of the students in the control and intervention groups at baseline were similar (Table 1). The mean age of the student was 7.59±0.53y in the control group and 7.41±0.54y in the intervention group (P<0.05). There were no significant baseline differences between the control and intervention groups in gender, height and weight. Moreover, the information from the questionnaire indicated that there was also no statistically significant difference in the time of outdoor activities and the proportion of myopia in parents between the two groups (Table 2).

The prevalence of myopia in this study at baseline was 8.5% in the control group and 10.1% in the intervention group, with no significant intergroup difference (P=0.723). The mean SER was -0.34±1.07 D in the control group and -0.39±1.01 D in the intervention group, and there was no significant difference between the two groups (P=0.256). The mean AL was 23.08±0.83 mm in the control groups and 23.09±0.81 mm in the intervention groups (P=0.797). Furthermore, no significant difference in ACD, CC, and white to white distance between the two groups was observed (all P>0.05; Table 2).

Table 3 Myopia incidence, SER and AL at 3-year follow-up[a]

Parameters	Control group	Intervention group	Difference (95%CI)	*P*
Cumulative incidence of myopia				
Incidence of myopia (%)	207/784 (26.4)[b]	164/774 (21.2)[b]	5.2 (3.7, 10.1)	0.035
3-year follow-up				
Axial length (mm)	0.77±0.36	0.72±0.32	0.05 (0.01, 0.09)	0.003
Spherical equivalent refraction (D)	-0.81±1.06	-0.63±0.90	-0.18 (-0.28, -0.08)	<0.001

[a]The calculation on all outcomes was based on right eye data only. [b]Cumulative number of cases of incidence myopia/number of analyzed participants (%). SER: Spherical equivalent refraction; CI: Confidence interval; AL: Axial length.

The three-year cumulative incidence rate of myopia was 26.4% (207 incident cases among 784 eligible participants at baseline) in the control group and 21.2% (164 incident cases among 774 eligible participants at baseline) in the intervention group, with significant intergroup difference (difference of 5.2%; 95%CI, 3.7% to 10.1%; *P*=0.035; Table 3).

Cumulative change in SER after three years was significantly less in the intervention group than in the control group (mean of -0.63 *vs* -0.81 D, respectively; difference of 0.18 D; *P*<0.001). Cumulative elongation of AL after three years was less in the intervention group than in the control group (mean of 0.72 *vs* 0.77 mm, respectively; difference of 0.05 mm; *P*=0.003; Table 3). No any adverse event was reported during this study.

DISCUSSION

To our knowledge, this investigation was the first to analyze the outdoor natural light and transform the school light into an ANL. Prospective control design in a large population contributed to high-quality evidence for ANL for myopia prevention and control. A recent Meta-analysis by Ebenezer[20] compared the myopia control affect by red light, violet light, or full-spectrum light ranking as the first, second, and third most effective wavelengths for impeding AL elongation and SER progression. The intervention by full-spectrum light brought an average reduction of 0.06 mm in AL and 0.11 D in SER, which is similar our study.

Intervention at the early school age at 8, a reduction incidence of 5.2% indicate a delighted outcome for further myopia control. Involvement of natural light or ANL has the potential into a standard for government in each classroom. A previous study conducted by Zhou *et al*[21] in Yangjiang, China, designed a bright classroom (Figure 5) that allowed an abundant sunshine entry and prevented myopia. However, this design filters out some wavelengths of sunlight, so the classroom light isn't natural, moreover, glass can produce a significant greenhouse effect, and this study does not show final result. Even if it is effective, it is still a huge project to transform the existing classroom structure in China, which is difficult to promote in practice. Using ANL instead of traditional light in classroom to control myopia in children is a simple, economical and feasible way to implement.

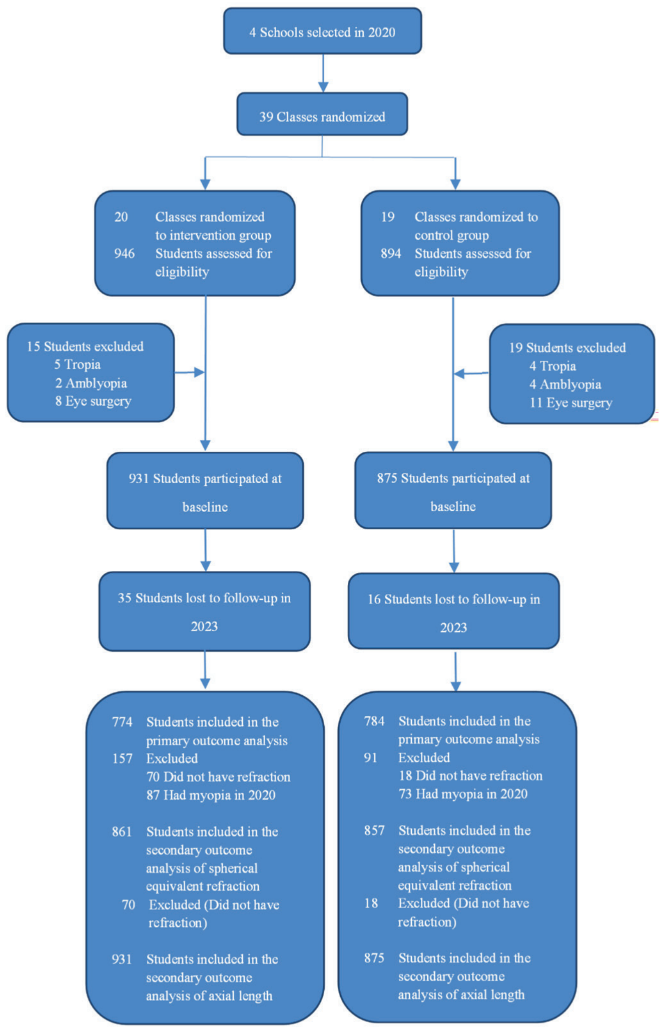

Figure 4 Group of subjects and number of follow-up.

Figure 5 External structure of the bright classroom.

Human evolution spanning millions of years has yielded adaptations to the natural environment. The human eye, an optical receiver, has undergone continuous evolution, achieving emmetropization under natural light. The theoretical elimination of nearsighted individuals due to reduced distance vision aligns with survival of the fittest principles. While historical human activity synchronized with natural light patterns, societal and technological advancements have ushered in indoor work and nighttime activities illuminated by artificial light. This artificial light lacks the full natural light spectrum, prompting myopia as an adaptive response for near-distance tasks. Some cases progress to high myopia, involving structural ocular changes and complications culminating in irreversible blindness. Thus, despite myopia's adaptive nature, controlling childhood progression is pivotal for averting complications and enhancing visual quality.

Full spectrum lighting involved a series method of myopia control. Possible mechanism included high illuminance, dopamine stimulation and short spectral induction. First, Outdoor illuminance; outdoor light illuminance is typically 10-1000 times higher than indoor light illuminance[22-23]. High-intensity light can stimulate the constriction of pupils and deepen the vision field depth thereby slowing down myopia development, which is consistent with the defocus hypothesis[24-25]. Several cross-sectional studies and longitudinal epidemiological studies conducted over the past decade suggests that adequate outdoor activity time among adolescents is an effective way for myopia prevention[26-29]. Second, dopamine is an important retinal neurotransmitter and plays an important role in the occurrence and development of myopia[30-31], literature proves that bright light stimulates the retinal dopamine release, which can prevent eyeball growth[32-33]. Third, some scholars believe that outdoor activities affect myopia progression because of spectra tendency to long wavelengths and far-sighted defocus to retina stimulating the growth of AL. On the contrary the ANL has a respectively short wavelength towards natural light, which can delay or prevent myopia[34-35]. Animal experiment on different wavelength environments revealed that animals in the long wavelength group mostly develop myopia, while those in the short wavelength environment developed hyperopia[36-37]. The results from differences among different lights can produce refractive and AL changes, and this effect can exist independently of the light intensity. We speculated the lower incidence of myopia in the intervention group may be related to short wavelength in ANL. More studies are expected to confirm this conclusion in the future.

Though unclear mechanism for ANL on myopia, clinical observation proved certain benefit from sunlight and ANL. Several observational studies reported that the development of myopia has seasonal fluctuations, and is slower in summer than in winter, suggesting that its occurrence and development might be related to sunlight[38]. Yi and Li[39] speculated that exposure to more natural light during outdoor activities is one of the reasons for delaying myopia. Furthermore, a study conducted by Cui *et al*[40] also indicated that with the increase of sun time, the growth of AL and myopia slowed down, while shortened time had opposite effects, suggesting that children should increase outdoor time to prevent and control myopia.

Due to racial dominance in Asian, myopia control is requiring for more intense method. Spectral advantage from red light showed obvious clinical outcome. In a recent randomized clinical trial conducted by Jiang *et al*[41], children with simple myopia received repeated low-level red-light (RLRL) intervention for one year, their 12-month follow-up results showed that the AL in the intervention group increased by 0.13 mm, while that in the control group increased by 0.38 mm on average, with an average intergroup difference of 0.26 mm. In terms of secondary outcome, the mean progress of SER was -0.20 D in the RLRL intervention group and -0.79 D in the control group, and the mean difference between the two groups was -0.59 D. The results showed that RLRL therapy delayed the progression of myopia by 76.6%. The study concluded that RLRL therapy can effectively control the progression of myopia in children aged 8-13 in China. It is also speculated that red light increases choroid blood circulation, improves choroid ischemia and hypoxia, and thus delays myopia progression. In current study, we found that red light was almost absent from the classroom spectrum in the control group, while the color rendering index (CRI) of red light in the intervention group was as high as 93%. Although the intensity of treatment with red light alone is very little, the long-term cumulative effect can improve choroid circulation, thus reducing the occurrence of myopia in children. At the same time, low intensity can avoid the potential risk of fundus damage caused by high-intensity red light.

The secondary outcome of this study showed that elongation of AL was 0.77±0.36 mm in the control group, and that was 0.72±0.32 mm in the intervention group, the difference between the two groups was 0.05 mm, and there was significant difference in statistical analysis (P<0.05). AL measurement is not subject to the subjective influence of children and is currently a very important objective indicator for myopia follow-up and monitoring. Combined with the results of myopia incidence, this study concluded that ANL can effectively reduce myopia incidence in children in China.

The shortcoming of this study includes that the children were not treated with cycloplegia, and a new myopia epidemiological definition was adopted. In other words, the combination of an SER and visual acuity can reduce the side effects caused by cycloplegia and the possible reduction of children's participation rate, and improve the compliance of children's examination. The comparative study showed that combining vision with SER is more reliable than simply using SER, and it also provided scientific objective data on myopia[19]. Due to the strong ophthalmic regulation of children, myopia prevalence is relatively higher in practice. However, in this study, the two groups adopted the same standard, and the sample size was relatively large, which could reduce the influence of NCR.

In conclusion, in this prospective, randomized control, intervention study, we found that among 8-year-old student in Foshan, China, ANL in classroom compared with traditional light resulted in reducing incidence rate of myopia, delaying progression of SER, and slowing elongation of AL over the next three years. It is a safe, simple, economical, and effective way for preventing and controlling myopia in children.

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