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RESEARCH

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Intensive outdoor activity for 1 week increases choroidal thickness in Japanese schoolchildren: a prospective observational study

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Abstract

Background Outdoor activity is important to prevent myopia progression among schoolchildren, and maintaining the choroidal thickness is important to retard myopia progression. However, no research has reported the effects of short-term intensive outdoor activities on the choroidal thickness. This institution-based prospective observational study aims to assess the impact of outdoor activity for 1 week during a camp program to study ocular parameters including the choroidal thickness.

Methods The intensive outdoor activity program included an average of 6.15 ± 2.98 h of daily time spent outdoors during the camp on subsequent days for 1 week at a low-altitude mountain camp. Twenty-four children participated in this program.

Results The main outcome was the change in the choroidal thickness compared with baseline. The data were measured at the beginning and end of the program over the course of 1 week and the changes analyzed. The mean age of the participants (50% female) was 11.5 ± 0.5 (standard deviation) years, and the mean changes were as follows: the refractive error became more positive, the axial length decreased, and the choroidal thickness (μm) increased, respectively, by 0.21 ± 1.35 diopters ($P = 0.742$), -0.01 ± 0.02 mm ($P = 0.241$), and 30.7 ± 20.3 μm ($P < 0.001$).

Conclusion The results suggested that intensive outdoor activity for only 1 week increased the choroidal thickness in Japanese schoolchildren.

Keywords Outdoor activity, Choroidal thickness, Myopia

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Background

The increasing prevalence of global myopia is a relatively recent social health problem [1]. The prevalence of myopia even in young Japanese children is increasing drastically and we reported the overall myopia rate as about 50% in kindergarteners [2], 70% in elementary schoolers, and 90% in junior high schoolers in Tokyo although the non-cycloplegic refraction was used as a method for assessing myopia resulting in an overestimated prevalence [2, 3], while the rapid explosion of myopia is significant in East Asia and Southeast Asia [4]. Treatments to prevent myopia progression include eyedrops such as topical atropine [5], contact lenses [6], orthokeratology [7], and spectacle lenses [8], which in some studies are efficacious when treatments are combined [9, 10]. The continuous progression of myopia not only increases the risk of high myopia but also any myopic status is associated with other eye diseases such as retinal detachment and glaucoma [11, 12]; therefore, expedited intervention against myopia progression from childhood and the development of a new therapeutic strategy are urgently needed.

Outdoor activity is an evidence-based environmental factor that retards myopia progression [13]. Previous studies have provided evidence that lighting prevents myopia progression in animals even for a short intensive period [14–16]. Wu et al. [17] reported that school-based intervention of 2 h outside over the course of a year prevented myopia progression. To the best of our knowledge, no studies have explored the relationship between intensive outdoor activity for a short time (i.e., 1 week) and the ocular biometry such as the choroidal thickness in children whose eyes are growing. The choroid is in the posterior eye between the sclera and retina. The choroidal thickness is correlated with myopia and axial lengths (ALs) [18]. We expected that the choroidal thickness is a predictor of myopia, because a previous study showed that the elongation followed choroidal thinning in mice and humans [19–21].

During outdoor activity, sunlight exposure and the outdoor light environment might be crucial to retard myopia [17, 22, 23]. We found that a certain wavelength of sunlight, from 360 to 400 nm (violet light [VL]), which is abundant outdoors but nonexistent indoors, is essential to prevent myopia through the non-visual photoreceptor, OPN5 [24]. Based on the finding that exposure to VL over a 6-month period increased the choroidal thickness in children [25], we hypothesized that a 6-month camp study should be designed to determine the changes in choroidal thickness. However, it is not practical to conduct a 6-month camp and the precise relationship between VL exposure and outdoor activities remains unclear. This prospective study was conceived to first determine how the choroidal thickness would change in children during a 1-week, low-altitude mountain camp at an elevation of 1,738 feet (530 m).

Methods

Study design and study populations

This prospective observational study was conducted in Gunma, Japan. The National Akagi Youth Friendship Center organized a summer camp in 2014 to develop childhood health. The recruitment period for this study was from May 28, 2023, to June 20, 2023. Our group joined the program in 2021 to assess the effect of intensive outdoor activity on the eyes. Twenty-four elementary schoolchildren (fifth and sixth graders) and first and second graders in a junior high school were included in the study.

The Keio University School of Medicine Ethics Committee approved this interventional study (approval number: 20210068, ethics approval date: June 8, 2021), which adhered to the tenets of the Declaration of Helsinki. The participating students and their parents provided written informed consent. Informed assent was obtained from the participants. The participants did not design, conduct, report, and plan the study but took part in an intensive outdoor activity program, i.e., about 4 h on the first, more than 5 h on the second and sixth days, and from 7 to 10 h daily on subsequent days for a total of 7 days during the 2023 summer vacation (August 13–20) at the National Akagi Youth Friendship Center. The base camp is located at N36.28° and E139.7° at an elevation of 1,738 feet (530 m) in the Akagi Mountains.

The program included indoor workshops and lectures (more than 2 h/day). To account for diurnal variations, eye examinations were conducted at the same time, from 13:00 to 15:00 at the beginning and end of the program (Fig. 1). Outdoor activities in the camp included mountain climbing for 4 days, during which the children began climbing in the morning and continued in the activity for over 6 h for 3 days, and outdoor cooking (Fig. 1).

Sample size calculation

The sample size calculation was based on hypothesis testing for the difference in paired population means (paired t-test). The sample size was determined using an exact method based on the noncentral t-distribution. Assuming a correlation coefficient of 0.9 between the pre-values and post-values, the required sample size was calculated to be 17. This determination was made under the condition that the change in choroidal thickness was 30 μm, the standard deviation was 80 μm as previous results in the same camp program, α was set at 0.05 (two-sided), and 1-β was set at 0.90. Assuming a dropout rate of 25%, the minimum sample size required was 23 participants. Since 24 individuals expressed their willingness to participate, the study included all 24 participants.

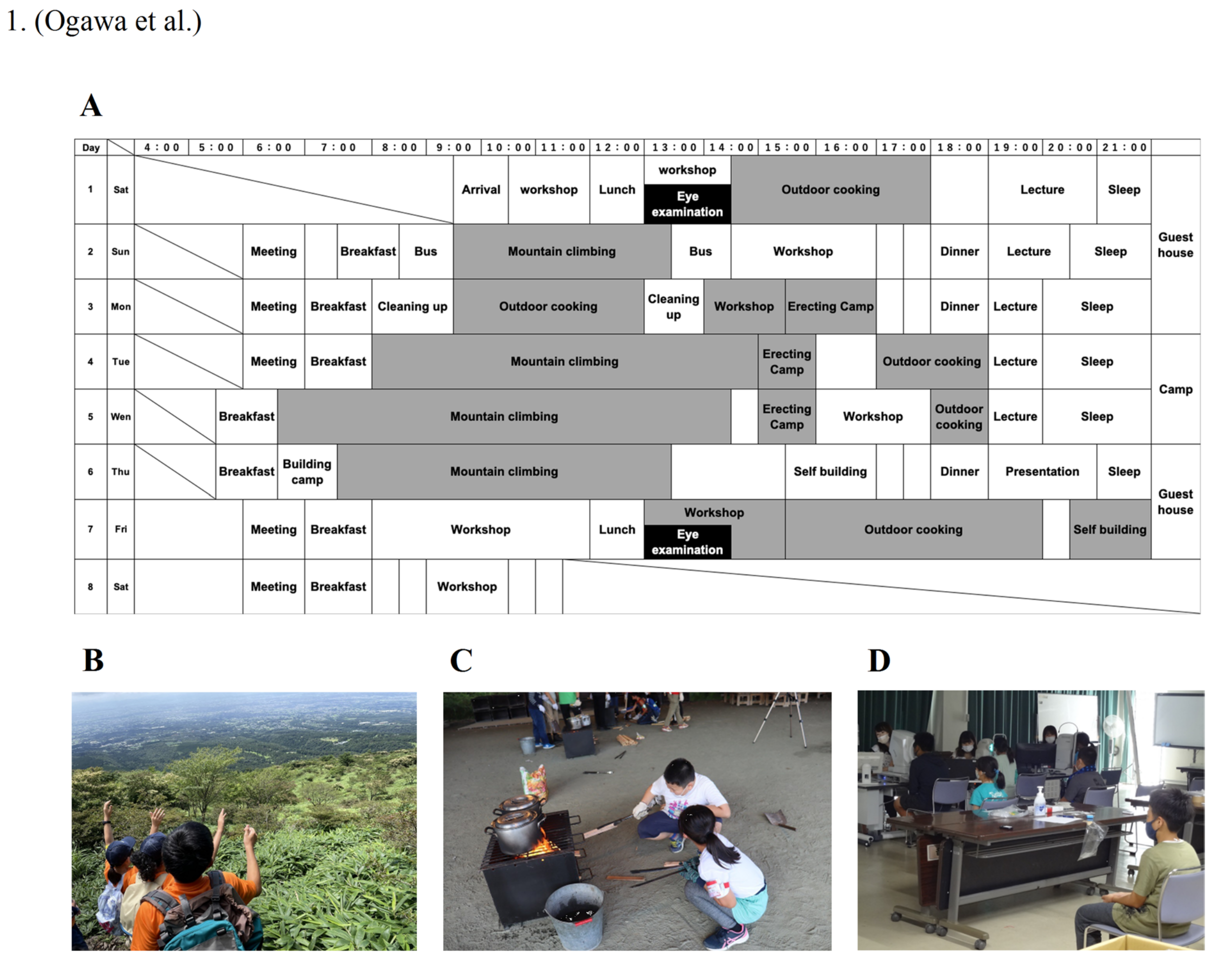

Fig. 1 Intensive 1-week outdoor activity program. **A**, Intensive outdoor activity program. The children spent time outside on subsequent days for a total of 7 days. The gray bars indicate outdoor activity, black eye examinations, and white indoor activity, meals and meetings. **B-D**, Representative pictures of the "Breakthrough camp" and the eye examination at the National Akagi Youth Friendship Center, Gunma, Japan. **B**, Mountain climbing. **C**, Outdoor activities such as cooking. **D**, Eye examination at the center during the camp

Ocular measurements

Eye examinations included measurement of the non-cycloplegic refraction using the HOYA iTrace Surgical Workstation (Tracey Technologies, Houston, TX, USA) and AL and corneal thickness using swept-source optical coherence tomography (SS-OCT) biometry (IOLMaster700, Carl Zeiss Meditec AG, Jena, Germany), choroidal thickness using spectral-domain OCT (RS-330, NIDEK, Aichi, Japan), tear fluid volume (Schirmer test: Clement Clark®, Essex, UK) in the camp center at the same times (13:30 – 15:00) (Fig. 1A) at baseline and the end of the program, and a questionnaire including lifestyle, familial history of myopia, time spent on near-vision activities, use of smart devices, and outdoor activities in general [3]. Since the maximal score of the Schirmer test was 35 mm, scores above 35 mm are calculated as 35. Ultraviolet A (320–400 nm) irradiance (μW/cm2) was measured using a digital ultraviolet A meter (CHY732, CHY Firemate Co., Ltd., Tainan, Taiwan). The range of the wavelength was 320 to 400 nm. The data were collected in the base camp and the mountains in Gumma during the camp in the summer (7 a.m., east, N36.28°, E139.7°, 1,738 feet (530 m) and 10 a.m., east, N36.53°, E139.2°, 5180 feet [1,579 m]). We also evaluated the subfoveal choroidal thickness as previously reported [26] and used the B-scan superfine mode for the enhanced visibility and deeper penetration of the choroid with the denoising software installed in the commercial devices in this study. Briefly, the outer margin of the retinal pigment epithelium was considered as the anterior margin of the choroid and the choroidal–scleral interface as the posterior margin of the choroid. The image was exported to ImageJ (National Institutes of Health, Bethesda, MD) and the borders of the choroid were drawn by connecting the marked locations, leading to the calculation of the measured choroidal thickness at the foveal center. Assessment of the choroidal thickness including image tilt adjustment was conducted manually and the same person (who was unmasked) carried

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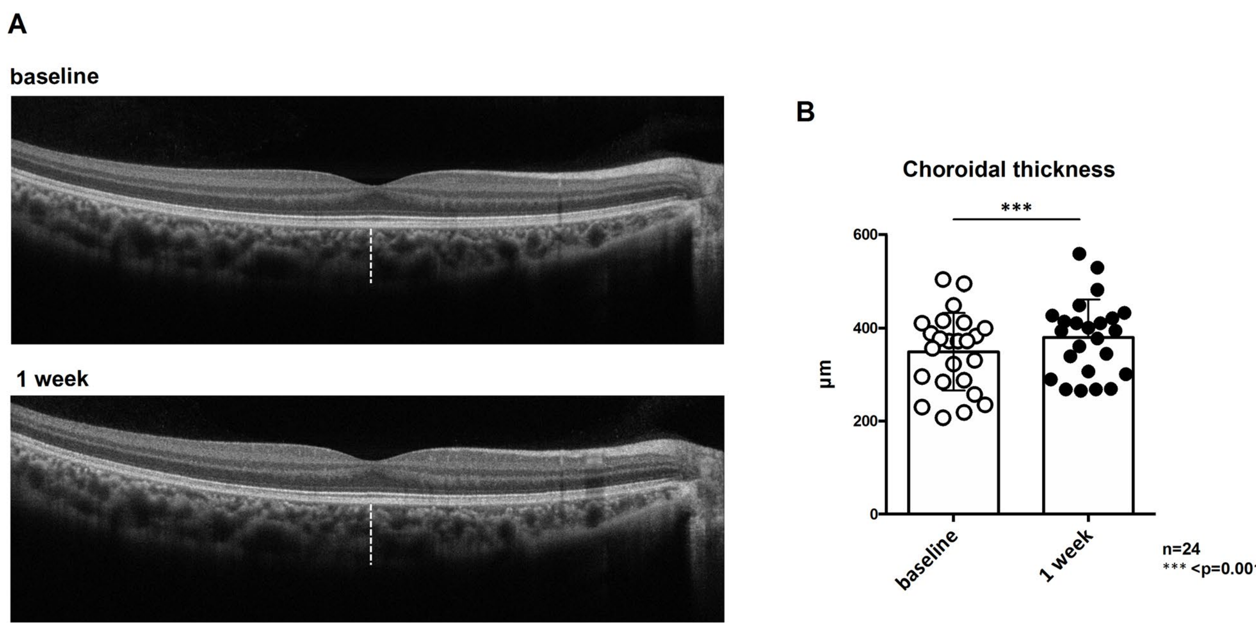

Fig. 2 Comparison of the choroidal thicknesses at baseline and after 1 week of intensive outdoor activity. **A**, Representative swept-source-optical coherence tomography images of the choroidal thicknesses (arrows) at baseline (upper) and after 1 week of intensive outdoor activity (lower). **B**, The choroidal thicknesses at baseline and after 1 week of intensive outdoor activity were, respectively, 349.0 ± 81.5 and 379.7 ± 79.9 µm (*P* < 0.001)

Table 1 Comparison of patient characteristics between baseline and after 1 week of intensive outdoor activity

	Baseline (*n* = 24) (mean ± SD)	**1 Week (*n* = 24) (mean ± SD)**	***P* Value***
Male (%)	50		
Refractive error (D)	-3.01 ± 2.21	-2.89 ± 2.27	0.742
AL (mm)	24.52 ± 1.17	24.51 ± 1.16	0.241
Subfoveal choroidal thickness (µm)	349.0 ± 81.5	379.7 ± 79.9	**< 0.001**
Corneal thickness (µm)	543.1 ± 39.0	545.3 ± 39.3	**0.022**
Retinal thickness (µm)	214.0 ± 15.7	213.8 ± 17.7	0.924
Anterior chamber depth (mm)	3.84 ± 0.28	3.82 ± 0.29	0.055
Lens thickness (mm)	3.29 ± 0.11	3.28 ± 0.12	0.182
Corneal diameter (mm)	12.2 ± 0.32	12.3 ± 0.35	0.091
Schirmer test (mm)	21.8 ± 12.7	18.7 ± 13.4	0.163

SD, standard deviation; D, diopters

*Wilcoxon signed-rank test

out all the analyses at baseline and the end. For repeatability, the same examiner segmented a subset of images twice with a time gap between sessions. The first measurement was conducted as a practice trial, and the second measurement was adopted as the final assessment. The segmentation protocol states that a line was drawn along the outer border of the RPE and the inner border of the choroidal-scleral interface, and the measurements were performed vertically downward from the fovea to the inner border of the choroidal-scleral interface [27, 28] (Supplemental Fig. 1). The examiner performing the manual segmentation underwent a training process that included reviewing anatomic landmarks and segmentation guidelines by an expert-determined reference, practicing segmentation on a training dataset under expert supervision, and conducting quality checks to minimize variability.

Statistical analyses

These parameters were analyzed at the beginning and end of the program using the Wilcoxon signed-rank test (Table 1). Data from the right eyes were analyzed because there was no significant difference between the right and left eyes in the AL and refraction (spherical equivalent [SE]) (AL, baseline [$P = 0.94$, $r = 0.97$], 1 week [$P = 0.95$, $r = 0.97$) and the SE, baseline [$P = 0.93$, $r = 0.93$], 1 week [$P = 0.98$, $r = 0.94$]). In addition to that, the Pearson correlation coefficient between the refractive errors, ALs, and choroidal thicknesses of the right and left eyes were, respectively, 0.953, 0.979, and 0.767. All statistical analyses were performed using statistical analysis software (SPSS for Mac, version 28.0, IBM-SPSS, Chicago, IL, USA). All P values were considered significant if they were < 0.05.

Results

Twenty-four children participated in this program and informed consent and assent were obtained from all participants. The characteristics of the participants are as follows. Briefly, age, height, weight, time spent outdoor per day, time spent in near work per day, reading distance, time sleeping per day, and percentage of participants who wore glasses for myopia and parents with myopia at baseline were, respectively, 10.5 ± 0.5 years old, 144.7 ± 7.7 cm, 38.3 ± 9.0 kg, 105.7 ± 51.1 min, 266.0 ± 174.7 min, 24.9 ± 5.36 cm, 486.9 ± 113.2 min, 50%, 4.2% (neither parent is myopic), 37.5% (one parent is myopic), and 54.2% (both parents are myopic). The time spent in near work exceeded 4 h before attending the camp. The daily time spent outdoors during the camp was an average of 6.15 ± 2.98 h.

The maximal ultraviolet A (320–400 nm) irradiance in the base camp and the mountains in Gunma during the camp in the summer were, respectively, 1,800 ± 34.6 and 4,127 ± 30.6 μW/cm^2 (7 a.m., east, N36.28°, E139.7°, 1,738 feet (530 m) and 10 a.m., east, N36.53°, E139.2°, 5,180 feet [1,579 m]).

After 1 week of the camp program, the choroidal thicknesses increased significantly by 30.7 ± 20.3 μm (standard deviation, $P < 0.001$) (Fig. 2). The baseline and final choroidal thicknesses were, respectively, 349.0 ± 81.5 and 379.7 ± 79.9 μm. The baseline and final values of the central corneal thicknesses, were, respectively, 543.1 ± 39.0 and 545.3 ± 39.3 μm ($P = 0.022$). The examinations were conducted at the camp at the same times (13:30 – 15:00) (Fig. 1A) at baseline and the end of the program. Due to the program schedule, the baseline was measured immediately after the start of the program on the first day of the camp. To account for circadian rhythms, measurements at the same time were taken. Day 7, the day before the final day of the camp, was set as the final measurement.

The mean refractive errors (SE) did not differ significantly between the beginning and end of the camp program, -3.01 ± 2.21 diopters (D) vs. -2.89 ± 2.27 D ($P = 0.74$). The mean AL and retinal thickness also did not differ significantly between the beginning and end of the camp program, 24.52 ± 1.17 mm vs. 24.51 ± 1.16 mm ($P = 0.241$) and 214.0 ± 15.7 μm vs. 213.8 ± 17.7 μm ($P = 0.924$). The tear fluid volume, anterior chamber depth, lens thicknesses, and corneal diameter also did not differ significantly between the beginning and end of the camp program (Table 1).

Discussion

We found that short, intensive outdoor activity for only 1 week increased the choroidal thickness in Japanese schoolchildren. We collected the data at the beginning and end of the camp program and not in a hospital or clinic.

Regarding outdoor activity, myopia researchers have provided evidence that outdoor activities such as sports or playing outside prevented myopia progression [29–31]. He et al. reported that an additional 40 min of open-air classes on weekdays and encouragement of outdoor activity on weekends significantly reduced myopic shifts during the following 3 years [32]. The choroidal thickness might be useful to evaluate ocular biometric changes in the short term, because the results from the current study showed the ocular effects resulting from outdoor activities for 1 week. Intensive outdoor activity for only 1 week might be sufficient to increase the choroidal thickness but not the AL and SE.

The thinning of the choroidal thickness is associated with myopia in young children [18, 33]. The choroidal thickness in children is reported to be associated with high myopia as children grow into adults [33]. This change of the choroidal thickness also is related to the SE and AL [34]. The recent development of SS-OCT enables more precise evaluation of the choroidal thickness. Several studies [35–37] have reported that outdoor activity increased the choroidal thickness. After 18 months of outdoor exercise (30 min/day), the choroidal thickness of children aged 10 to 15 years increased by 13 ± 22 μm [35]. After 24 months of outdoor activity (over 2 hours/day) and wearing of VL-transmitting eyeglasses, the choroidal thickness of a 4-year-old highly myopic child increased by 115.7 μm [36]. With 1 week of light exposure in the morning (30 min/day), the choroidal thickness increased by 5.4 ± 10.3 μm in healthy young adults aged 20 to 29 years [37]. Long-term outdoor activity increases the choroidal thickness and reduces the AL elongation. However, a previous study reported that outdoor activity for adults resulted in choroidal thinning, although the study did not control for confounders such as caffeine, smoking, and visual activity (from a phone) during the 2-hour unsupervised activity [38]. The study included adults who were exposed to the outdoor environment for only 2 hours. A previous study proved that long-term light exposure, such as 10 h for chicks, increased the choroidal thickness, even though short-term light exposure for 6 h decreased the choroidal thickness [39]. We reported that

VL prevents myopia progression in mice and humans [24, 40]. We performed a pilot study for 6 months in which the participants wore eyeglasses that emitted VL of 310 μW/cm^2 from the frames (VLf), and showed that changes in the choroidal thickness in the VLf group increased significantly compared with the control group [25]. Moreover, previous studies have shown that the cerebrospinal fluid pressure and high-altitude exposure with hypoxia were associated with a thicker choroid via the choroidal blood flow [41–43]. It is difficult to distinguish the effect of light from other factors in determining what caused the choroidal thickening unless we recheck the choroidal thickness a few days after returning from camp to verify if the choroidal thickness change is permanent or transient. As various conditions, such as age, physical activity and exercise, outdoor exposure duration, and frequency may affect the choroidal thickness (Supplemental Tables 1 and 2), future studies are needed to confirm the findings. In the current study, the choroidal thickness increased by 30.7 μm during an outdoor camp that lasted only 1 week. The manner by which the choroidal thickness regulates myopia remains unclear; however, advancement of this research will lead to elucidation of the detailed mechanism.

The current study also found that the corneal thickness increased significantly (+2.2 μm) at the end of the program. Tear fluids are included in the corneal thickness using SS-OCT, and the central tear film thickness reported in the past was 4.79 ± 0.88 μm [44]. We did not observe the tendency for increased tear levels at the end of the camp program (Table 1). Further investigations are needed to determine the tear volume and the tear film thickness that causes the changes in the corneal thickness.

This study also found no statistical difference in the SE between the beginning and end of the camp program, while the choroidal thickness increased over the course of 1 week. This is an important phenomenon in understanding the mechanism by which outdoor activity inhibits myopia progression. Further studies are clearly needed to determine the extent to which the increased choroidal thickness can be maintained over a short period of time and whether other factors contribute to these phenotypes. Taken together, our results may provide a new strategy to control choroidal thickness through outdoor activities.

The current study had some limitations. First, this study was not completely reflective of the children in Japan as a whole because only the 24 students in the Akagi youth national center were evaluated. There might be a volunteer bias, because the children and their parents are strongly motivated to participate in outdoor activities such as the camp program. Second, we did not compare their findings with those of children who did not participate in the camp program as controls. Third, the measurements did not include vessel density and choroidal vascularity index (CVI), and the questionnaire did not include caffeine intake and exercise, which are thought to be related to choroidal thickness. Fourth, the non-cycloplegic refraction was performed during the eye examinations. Fifth, we did not measure the spectral characteristics of light other than ultraviolet A. Sixth, the graders who analysed the OCT images were not masked. Finally, we did not monitor physical activity and light exposure objectively.

Conclusion

We conducted eye examinations for schoolchildren in their early teens before and after a 1-week program at a low-altitude mountain summer camp. Our results suggested that participating in the outdoor camp for 6 h per day for only 1 week increased the choroidal thickness.

Abbreviations

AL	Axial length
CVI	choroidal vascularity index
D	Diopters
SE	Spherical equivalent
SS-OCT	Swept-source optical coherence tomography
UVB	ultraviolet B
VL	Violet light

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions

MO, HT, TK, and KT made substantial contributions to the design of this study. MO, EY, and KM collected the data. MO analyzed the data. MO, EY, HT, KM, AH, KN, TK, and KT interpreted the data. MO, EY, KM, and HT drafted the manuscript. JM and KF administrated technical or material support. All authors have read and approved the final manuscript.

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Data availability

The data will be available on request to corresponding authors.

Declarations

Ethics approval and consent to participate

The Keio University School of Medicine Ethics Committee approved this interventional study (approval number: 20210068, ethics approval date: June 8, 2021), which adhered to the tenets of the Declaration of Helsinki. The participating students and their parents provided written informed consent. Informed assent was obtained from the participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.
Patent: Outdoor activity is related to violet light. (KT, TK, HT and KN have applied for a patent).

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