BMJ Open

Factors protecting against progression of myopia in school students exposed to societal change in Vietnam: a 3-year cohort study

Xuan Minh Tri Tran ,[1,2] Hoang Thuy Linh Nguyen ,[2] Thao Vi Tran ,[1,3] Kaoruko Seino ,[1,4] Kyoko Ohno-Matsui ,[5] Tae Igarashi-Yokoi ,[5,6] Thang Van Vo,[2] Keiko Nakamura [1]

To cite: Tran XMT, Nguyen HTL, Tran TV, *et al*. Factors protecting against progression of myopia in school students exposed to societal change in Vietnam: a 3-year cohort study. *BMJ Open* 2025;**15**:e085853. doi:10.1136/bmjopen-2024-085853

► Prepublication history for this paper is available online. To view these files, please visit the journal online (https://doi.org/10.1136/bmjopen-2024-085853).

Received 29 February 2024
Accepted 22 November 2024

For numbered affiliations see end of article.

Correspondence to
Professor Keiko Nakamura; nakamura.ith@tmd.ac.jp

ABSTRACT

Objectives To elucidate the incidence of myopia, progression of refractive error, axial length (AL) elongation and factors associated with myopia in secondary school students in Vietnam.

Design Prospective cohort study.

Settings Hue Healthy Adolescent Cohort Study, Hue City, Vietnam.

Participants 3-year longitudinal data were available for 355 secondary school students (mean age 11.60±0.36, 46.8% girls). Noncycloplegic refraction and AL measurements were performed at baseline and the 3-year follow-up examinations.

Primary and secondary outcome measures The primary outcomes were myopia incidence and progression. Myopia, emmetropia and hyperopia were defined as spherical equivalent (SE)≤−1.0 diopters (D), −0.5 D<SE < +0.5 D and SE ≥ +0.5 D in the right eye, respectively. The cumulative incidence of myopia was defined as the proportion of students who were not myopic at baseline but who subsequently developed myopia during the follow-up period. Factors associated with myopia incidence and progression were analysed using logistic and linear regression models, respectively.

Results Baseline mean SE and AL were −0.94±1.66 D and 23.36±0.93 mm, respectively. The cumulative and annual incidences of myopia were 40.6% and 12.5%, respectively. Spending more time outdoors was associated with a significantly decreased incidence of myopia (adjusted OR 0.499; 95% CI: 0.329–0.757), less myopic SE progression (β=0.337; 95% CI: 0.254, 0.640) and slower AL elongation (β=−0.289; 95% CI: −0.202 to −0.071). In contrast, a study using computers was significantly associated with greater myopic progression in SE (β=−0.184; 95% CI: −0.699 to −0.112) and AL elongation (β=0.208; 95% CI: 0.062, 0.263).

Conclusion This longitudinal assessment revealed both myopia incidence and progression and identified myopia-risk and myopia-protective behavioural factors in a Vietnamese cohort of secondary school students. The results highlight the high prevalence and considerable incidence of myopia, and the need for further effective strategies to reduce the risk of myopia by managing computer time and increasing outdoor time.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The strength of this study was the prospective cohort design with 3-year longitudinal data from secondary school students, with a high completion rate of 91.0%.
⇒ Ocular examinations conducted by trained ophthalmologists were performed at both baseline and follow-up surveys, collecting data on refractive error and axial length.
⇒ Noncycloplegic refraction was used during ocular examinations. To avoid overestimation of the prevalence of myopia in teenagers with active accommodation, a robust threshold for myopia of spherical equivalent (SE) ≤ −1.0 diopters (D) was applied.
⇒ The collection of risk and protective factors for myopia relied on questionnaire completion by students, introducing the possibility of recall bias.

INTRODUCTION

Myopia is a common cause of correctable vision loss, with uncorrected myopia remaining the leading cause of distance vision impairment globally.[1] Myopia is associated with compelling visual impairment and economic burden and increasing long-term negative impacts on the quality of life and academic performance in affected individuals.[2]

Myopia affects more than 100 million people globally.[3] It is estimated that, by 2050, 4.76 billion people, accounting for 50% of the world's population, will have myopia.[4] Myopia is most prevalent in East and Southeast Asia, affecting a surprisingly high proportion of children and young adults.[5–9] Among countries in these regions, including Vietnam, the prevalence of myopia has increased from 20%–30% to 80%–90% among school-leaving adolescents over the past 50 years, representing a threefold to fourfold increase.[10 11] However, while most prior studies were conducted in East Asian

countries such as Mainland China, Hong Kong, Taiwan, Japan and South Korea, evidence has been reported from a few Southeast Asian countries, such as Singapore,[12–15] raising the need for further investigations into myopia in this region.

The recent increase in myopia cases in Asian countries coincides with the increase in educational pressures on students.[7] Asian children often engage in substantial homework and extracurricular study from an early age. The intense competition at school leads them to spend most of their time studying indoors. A study in Taipei revealed that students engaging in after-school tutoring programmes for 5 or more hours per week faced an increased likelihood of developing myopia.[16] A study of Chinese primary school students in Beijing reported that increased axial elongation over 4 years was associated with increased indoor study time and reduced outdoor time.[17] Regarding behavioural and environmental factors, excessive near-work and studying, increased screen time on electronic devices and limited time spent outdoors in daylight have been discussed with the rise of myopia in the region.[18–21] Other associated factors for myopia addressed included being biologically female, a higher prevalence and severity of parental myopia and a higher level of parental education.[22–26]

Refractive errors such as myopia are emerging public health concerns in Vietnam. The country has generally experienced a relatively low prevalence of myopia, but it is expected to increase notably due to urbanisation, the growing emphasis on education, the widespread use of electronic devices, urbanisation and changing lifestyles.[27–29] In response to this concern, the Vietnamese Government sanctioned the Strategic Plan for the Prevention of Blindness in Vietnam, aiming towards the years 2020 and 2030.[30] However, reported evidence related to the prevalence and progression of myopia from Vietnam remains scarce, and most studies in the past are cross-sectional investigations. Therefore, it is important to obtain updated evidence on the prevalence of myopia in Vietnam, particularly among children and adolescents.

Understanding the incidence and progression of myopia and the protective as well as risk factors associated with myopia among school-aged children based on longitudinal observation is important for developing effective approaches to prevent, detect early signs of and manage myopia within this demographic. This is particularly significant in regions that have experienced the initial stages of urbanisation as Vietnam. Thus, this study aimed to elucidate the incidence of myopia, progression of refractive error, elongation of axial length (AL) and associated protective and risk factors among secondary school students in Vietnam by a cohort study.

METHODS

Study population

The Hue Healthy Adolescent Cohort Study is a 3-year school-based cohort study that included students attending secondary schools in urban areas in Vietnam. This study was approved by the Institutional Review Board of the Medical Schools of Tokyo Medical and Dental University, Japan, and Hue University of Medicine and Pharmacy, Vietnam. Students from secondary schools were enlisted along with permission from the Department of Education and Training in the Thua Thien Hue Province, Vietnam. The baseline study was conducted in 2018, and a follow-up study was conducted 3 years later.

Hue City is in the central region of Thua Thien Hue Province, central Vietnam. It encompasses an area of 266 square kilometres and includes a population of nearly 70 000 secondary school students. Participants for this study were selected using a multistage stratified cluster random-sampling design. In the baseline survey conducted in 2018, five secondary schools were randomly chosen from a pool of 23 public secondary schools in the study region. Subsequently, a random selection was made of sixth-grade students from four or five classes in each school, based on the size of the respective schools. The follow-up survey was conducted in 2021 when the COVID-19 pandemic was still prevalent in Vietnam, at three schools among the five. Statistically similar characteristics of students in the baseline survey were observed among the three schools that completed both baseline and follow-up surveys and the other two schools that only completed the baseline survey. There were no significant differences in the percentage of students' self-study time, attendance in extra classes, and time spent on indoor and outdoor activities. Among the 390 students initially enrolled at baseline at the three schools, 355 students completed an ophthalmic examination and a questionnaire in both surveys (91.0% completion rate). Students with severe ocular diseases other than refractive error, such as cataracts, were omitted. Finally, only the data of these 355 students in three schools who completed the ophthalmic examination both at baseline and at the 3-year follow-up were included in the cohort analysis of the incidence and progression of myopia.

Patient and public involvement

The participating secondary schools were involved in designing this research, its implementation and disseminating the results. Examinations were designed to meet the needs of participating students. All students were involved, and their parents or legal guardians have been explained about the nature of the study and provided consent. The study results were disseminated to the schools and study participants for further planning for students' health.

Procedures

All study participants underwent a comprehensive ocular examination, including visual acuity measurement, auto-refraction and AL assessment. Visual acuity was tested monocularly and binocularly at 5 m using a Landolt C chart under room illumination (about 100–300 lux). Refraction was performed in a

noncycloplegic state using an auto-refractometer (auto-refractor ARK-1, Nidek, Aichi, Japan). AL measurements were performed using an ultrasound biometer A-scan (ECHOScan US-4000, Nidek) by the contact method. Corneal anaesthesia was used to minimise the discomfort before measuring the AL with one drop of 0.5% proparacaine hydrochloride (Alcaine 0.5%, Alcon Laboratories, Fort Worth, TX, USA). Trained ophthalmologists performed all examinations. The same assessments were conducted during the initial baseline examination in 2018 and were subsequently repeated in the follow-up examination in 2021.

Participants also underwent a face-to-face interview with a trained staff team member, during which they completed the questionnaire developed at the Department of Global Health Entrepreneurship of Tokyo Medical and Dental University based on the Global School-Based Student Health Survey (GSHS) and Child Refractor Error Risk Factor Questionnaire.[31] The questionnaire was initially developed in English, then translated into Vietnamese and then back-translated into English to check the clarity and validity of the translation. Written informed consent was obtained from the guardian of each student to permit conducting the ocular examination and interviews with the student. The guardians were fully informed about the purposes of the research and how their results and responses would be used and stored. Examinations and interviews were conducted when students provided written informed assent in addition to their guardian's informed consent.

Definitions

The spherical equivalent (SE) was calculated by adding the sum of the sphere power to half the cylinder power. Because noncycloplegic refraction is known to overestimate the prevalence of myopia,[32] some studies have recommended using −1.0 diopter (D) instead of −0.5 D as a robust threshold to reduce false-positive results.[33–35] In this study, myopia was defined as an SE of −1.0 D or less in the right eye. In addition, emmetropia and hyperopia were defined as −0.5 D < SE < +0.5 D and SE ≥ +0.5 D in the right eye, respectively. The SE of the remaining range, −1.0 D < SE ≤ −0.5 D, was categorised as borderline. Data analyses focussed only on the right eye due to the strong correlation observed between the SE refraction in both the right and left eyes at baseline (Spearman correlation coefficient = 0.83, p < 0.001) and at the follow-up survey (Spearman correlation coefficient = 0.81, p < 0.001).

SE, cylinder diopters and AL were documented during both the baseline and follow-up assessments. The progression in AL and refractive error was determined by subtracting the respective baseline values from those obtained during follow-ups. The cumulative incidence of myopia was defined as the proportion of students who were not myopic at baseline but who subsequently developed myopia during the 39-month follow-up period.

Covariates

Covariate data were largely derived from questionnaire measures. The questionnaire included inquiries about participants' sociodemographic characteristics and behavioural factors, including the duration and nature of outdoor activities, indoor activities and studying. Some studies reported that the amount of time spent indoors and outdoors, and the time dedicated to studying are associated with myopia.[36–39] Furthermore, Vietnamese school students often attend extra classes after school, which are frequently held in cramped spaces with poor lighting, raising concerns about the development of myopia.[40] The study-related questions were on time spent self-studying after school per day (2 hours or less; more than 2 hours), attending extra classes after school (yes or no) and using a computer for studying (yes or no). The indoor time question was about the time engaged in the following indoor activities on weekdays and weekends: reading printed material for pleasure, playing video/computer games for pleasure, watching TV/movies and playing sports/exercising. The time spent outdoors question was on the time engaged in the following outdoor activities on weekdays and weekends: playing/walking and playing sports. The students' average number of hours spent daily on these indoor and outdoor activities was calculated using the following formula: ((hours spent on a weekday) ×5 + (hours spent on a weekend day) ×2)/7 and was later included in the analysis as a continuous variable.

Statistical analysis

In descriptive analyses, the parameters were presented as number (%), and mean±standard deviation (SD). The χ^2 test was used to test for differences between diagnoses of myopia, borderline, emmetropia and hyperopia of the right eye at baseline and follow-up examinations. The multicollinearity of independent variables included in the model was tested by the variation inflation factor (VIF) values, and they ranged from 1 to 3 showing statistical rationality to be included in the model. Then, logistic regression analyses were performed to investigate the associations between the incidence of myopia (dependent variable) and sociodemographic and behavioural factors (independent variables). The adjusted odds ratios (aORs) and its 95% CIs were calculated. Furthermore, among those without myopia at baseline, linear regression analyses were performed to explore the associations between the progression of myopia, the elongation of AL (dependent variable), and sociodemographic and behavioural factors (independent variables). The standardised regression coefficient beta and its 95% CI were calculated. Multivariable logistic and linear regression models were adjusted for age, sex, time spent self-studying, attendance in extra classes, usage of a computer for studying, time spent in indoor and outdoor activities, baseline SE and AL. No imputation was performed for the missing data. Data were analysed using SPSS software (IBM, Armonk, NY, USA), with the significance level set at p<0.05.

Table 1 Baseline characteristics of students who completed both baseline and follow-up examinations (n=355)

Baseline characteristics	Mean±SD
Age at baseline (years)	11.60±0.36
Sex, female, n (%)	166 (46.8%)
Time spent in self-study, more than 2 h/day n (%)	112 (31.5%)
Attending extra-class, yes n (%)	322 (90.7%)
Studying on computer, yes n (%)	149 (42.0%)
Daily time reading printed material indoors (h/d)	1.16±0.73
Daily time playing video game indoors (h/d)	1.38±0.67
Daily time watching TV indoors (h/d)	1.47±0.66
Daily time playing sports indoors (h/d)	0.48±0.72
Daily time playing/walking outdoors (h/d)	1.31±0.71
Daily time playing sports outdoors (h/d)	1.02±0.81

SD, standard deviation.

RESULTS

The baseline characteristics of the participants are presented in table 1. On average, the students were 11.60±0.36 years, with girls comprising just less than half of the sample. Most students lived with both parents. One-third of students spent more than 2 hours per day on self-studying, and over 90% of students attended extra classes after school. Two-fifths of students studied on the computer. On average, students spent about 1.5 hours per day playing and walking outdoors and about an hour per day on outdoor sports activities. Watching TV and playing video games were the two most popular indoor activities among students, each accounting for nearly 1.5 hours per day.

The total prevalence of myopia in students increased from 32.7% at baseline to 56.3% at the end of the 3-year and 3-month follow-up. Of the 239 students who were without myopia at baseline, 97 had developed myopia by the follow-up examination, yielding a cumulative myopia incidence of 40.6% and an annual incidence of myopia of 12.5% (table 2). Meanwhile, 142 students remained nonmyopic by the end of the follow-up period, indicating that their eye development followed a normal growth pattern without progressing into myopia. Table 2 also shows that the final incidence of myopia among students with hyperopia at baseline (6.7%) was significantly lower than that among students with emmetropia at baseline (40.8%), (p<0.001).

Table 3 shows the mean SE at baseline, the mean SE at follow-up and the mean progression of SE over the 39-month follow-up period in the entire population. Baseline mean SE and AL were −0.94±1.66 D and 23.36±0.93 mm, respectively. The cumulative refractive change and axial length change were −1.05±1.14 D and 0.78±0.44 mm (−0.32 D/year and 0.24 mm/year), respectively. Among the group without myopia at baseline, the mean progression of SE was −1.00±1.09 D, and the mean elongation of AL was 0.71±0.39 mm. Among the myopia, emmetropia and hyperopia groups at baseline, the greatest SE progression (−1.14±1.23 D) and the greatest AL elongation (0.93±0.51 mm) were both observed among the students in the myopia group over the 3-year follow-up period.

Logistic regression analyses were performed to determine the association between the incidence of myopia, sociodemographic characteristics and behavioural factors among the participants (table 4). After adjusting for baseline characteristics, the daily time spent playing sports outdoors was identified as a protective factor against myopia, with increased outdoor time reducing the risk of incident myopia (aOR=0.499; 95% CI: 0.329, 0.757). In contrast, studying on a computer increased the risk of incidence of myopia (aOR=1.899; 95% CI: 1.018, 3.542). Furthermore, refractive error at baseline was also significantly associated with the incidence of myopia (aOR=0.211; 95% CI: 0.105, 0.424), as students with lower SE at baseline were more likely to have developed myopia by the end of the follow-up period.

Table 5 presents the findings from the univariable and multivariable linear regression analyses of 3-year changes in SE and AL. After adjusting for baseline characteristics, the analysis revealed that daily time spent playing sports

Table 2 Diagnosis of myopia, borderline, emmetropia and hyperopia of the right eye at follow-up examination according to the diagnosis at baseline examination (n=355)

		Follow-up			
Baseline	N	Myopia n (%)	Borderline n (%)	Emmetropia n (%)	Hyperopia n (%)
Myopia	116	103 (88.8)	5 (4.3)	8 (6.9)	0 (0.0)
Borderline	52	31 (59.6)	9 (17.3)	11 (21.2)	1 (1.9)
Emmetropia	157	64 (40.8)	32 (20.4)	58 (36.9)	3 (1.9)
Hyperopia	30	2 (6.7)	1 (3.3)	22 (73.3)	5 (16.7)
All	355	200 (56.3)	47 (13.3)	99 (27.9)	9 (2.5)

Myopia: SE ≤ −1.0 D; borderline -1.0 D < SE ≤ −0.5 D ; Emmetropia: -0.5 D < SE < +0.5 D; Hyperopia: SE ≥ +0.5 D.
χ^2 test: p < 0.001.
SE, spherical equivalent.

Table 3 Spherical equivalent (SE) and axial length (AL) of the right eye according to the diagnosis of myopia, emmetropia and hyperopia at baseline and at follow-up examination

	Baseline		Follow-up		Progress in 39 months	
	Mean	SD	Mean	SD	Mean	SD
All students (n=355)						
SE	−0.94	1.66	−2.03	2.11	−1.05	1.14
AL	23.36	0.93	24.14	1.07	0.78	0.44
Students at risk for R eye myopia (nonmyopia) (n=239)						
SE	−0.04	0.46	−1.03	1.18	−1.00	1.09
AL	23.03	0.69	23.75	0.82	0.71	0.39
Students with R eye myopia at baseline (SE ≤ −1.0 D) (n=116)						
SE	−2.80	1.69	−3.96	2.17	−1.14	1.23
AL	24.03	1.01	24.96	1.08	0.93	0.51
Students with R eye emmetropia at the baseline (−0.5 < SE < +0.5 D) (n=157)						
SE	0.05	0.24	−1.04	1.14	−1.09	1.11
AL	23.05	0.67	23.76	0.80	0.70	0.35
Students with R eye hyperopia at baseline (SE ≥ +0.5 D) (n=30)						
SE	0.66	0.27	0.01	0.50	−0.66	0.57
AL	22.79	0.76	23.39	0.80	0.60	0.39

AL, axial length; SD, standard deviation; SE, spherical equivalent.

outdoors was significantly associated with less myopic progression in SE (β=0.337; 95% CI: 0.254, 0.640) and a slower elongation of AL (β=−0.289; 95% CI: −0.202 to −0.071). Conversely, students who used computers for studying experienced significantly greater myopic progression in SE (β=−0.184; 95% CI: −0.699 to −0.112) and more rapid elongation of AL (β=0.208; 95% CI: 0.062, 0.263). Daily time spent playing sports indoors was also associated with greater progression of SE and elongation of AL, despite these associations being marginally significant. Other behavioural factors, such as time spent on self-study and attending extra classes, were not significantly related to the progression of SE or the elongation of AL.

DISCUSSION

To our knowledge, no earlier longitudinal study has examined the incidence and progression of myopia among secondary school students in Vietnam. Our results highlighted a high prevalence and considerable incidence and progression of myopia among the participants. Using a computer for studying was associated with increased SE progression and AL elongation, whereas increased time spent playing sports outdoors was associated with a decreased incidence of myopia and decreased progression of myopic refractive error. Our study provided important implications for formulating myopia prevention strategies among school students in Vietnam.

Our study found that the mean elongation of AL was 0.24±0.16 mm/year, and the mean progression of SE was −0.32±0.35 D/year, over the 3-year follow-up period. Longitudinal studies conducted in different geographical and ethnic contexts have reported the progression of myopia in school-aged children. Compared with the results from some East Asian studies on myopia in children, this study showed a slower progression of myopia than among children in urban areas of China and Taipei. A study of 1997 Chinese children, aged 12.7±0.5, over a 2-year follow-up period, showed that the mean progression of SE was −0.48 D/year, and the mean elongation of AL was 0.24 mm/year.[41] Hsu *et al* reported that the mean progression of myopia in primary school children in Taipei was −0.42 D/year.[42] In comparison with other studies, our findings indicated a faster progression of SE and AL than those observed in studies from rural China (SE progression of −0.15 D/year and AL elongation of 0.11 mm/year over a 3.5-year follow-up period) and Russia (AL elongation of 0.19±0.17 mm/year, over a mean follow-up of 1.41±0.33 years).[43 44]

The current study also found that the cumulative and annual incidences of myopia were 40.6% and 12.5%, respectively. This finding showed lower incidence of myopia compared with findings from China, but a higher incidence than those reported in India among adolescents. For instance, a school-based study in Southwest China reported a 1-year incidence of myopia of 54.0% for seventh-grade students,[45] and another Chinese study found an annual incidence of nearly 30% among junior high school students.[46] In contrast, findings from India showed an annual myopia incidence of only 3.4% among urban school children.[47] In addition, the prevalence of myopia in our study population at follow-up examination

Table 4 Factors associated with the incidence of myopia among students at risk of myopia in the 3-year cohort study using logistic regression (n=239)

Baseline characteristics	OR (95% CI)	aOR (95% CI)
Age at baseline (years)	0.785 (0.395, 1.560)	0.912 (0.415, 2.003)
Sex		
Male	1	1
Female	1.634 (0.970, 2.752)	1.030 (0.552, 1.922)
Time spent in self-study		
2 hours or less	1	1
More than 2 hours	1.329 (0.765, 2.311)	1.282 (0.686, 2.395)
Attending extra classes		
No	1	1
Yes	1.314 (0.534, 3.231)	1.008 (0.360, 2.821)
Studying on a computer		
No	1	1
Yes	1.561 (0.924, 2.638)	1.899 (1.018, 3.542)*
Daily time reading printed material indoors	1.372 (0.955, 1.970)	1.415 (0.941, 2.127)
Daily time playing video game indoors	0.929 (0.627, 1.379)	0.958 (0.607, 1.513)
Daily time watching TV indoors	1.194 (0.791, 1.802)	1.386 (0.850, 2.261)
Daily time playing sports indoors	1.308 (0.926, 1.846)	1.484 (0.984, 2.238)
Daily time playing/walking outdoors	0.994 (0.693, 1.425)	1.072 (0.687, 1.671)
Daily time playing sports outdoors	0.653 (0.472, 0.902)*	0.499 (0.329, 0.757)**
Baseline SE	0.240 (0.128, 0.453)***	0.211 (0.105, 0.424)***
Baseline AL	1.029 (0.706, 1.501)	0.900 (0.574, 1.413)

*p < 0.05; **p < 0.01; ***p < 0.001.

was 56.3%, which is higher than that reported in other regions, such as in the USA (36.1% among children aged 5–17 years),[48] Ireland (22.8% among children aged 12–13 years)[39] and the Netherlands (22.5% at age 13 and 28.9% at age 18).[49] This notable prevalence and incidence of myopia observed in our study can be attributed to the inclusion of secondary school students from an urbanised Vietnamese area. These students often face intense academic pressure in a highly competitive educational environment. The demands of their rigorous study schedules, combined with increased use of electronic devices, are significant factors likely contributing to the elevated prevalence of myopia in this population.

Another finding of the current study was that the incidence of myopia among students who had hyperopia at baseline was significantly lower than that of students with emmetropia at baseline. With an increase in baseline SE hyperopia, there was a significant decrease in the occurrence of myopia. This suggests that the baseline SE serves as a reliable predictor for the onset of myopia in the future. Consistent with our study findings, the results from a prior cohort study demonstrated a significant correlation between the incidence of myopia and baseline refraction. Children with less hyperopic baseline refraction were found to be at a higher risk of developing myopia.[33] This factor was also well-documented in another cohort study conducted in Shanghai, China, which showed that baseline SE could be a simple and effective predictor of myopia.[50] Meanwhile, some children with myopia at baseline had progressed to emmetropia at the end of follow-up. The noncycloplegic refraction measurements show some degree of variation and some measurement errors could have been observed.

Near-work, including using computers, and outdoor activities were the two most frequently acknowledged risk and protective factors, respectively, that have been linked to myopia.[51–53] Our study also showed that these two factors were associated with the incidence and progression of myopia and elongation of AL, among school students. Research has shown that engaging in outdoor activities is correlated with a reduced likelihood of developing myopia.[12 34 54–58] In East Asia, several school-based interventions have also used the protective effect of outdoor time against the progression of myopia, such as in Singapore since 2008[12 14] and Taiwan since 2010.[59] In Vietnam, a study of secondary school students found that increased outdoor time was significantly linked to a reduced risk of developing myopia. Specifically, children who spent at least 2 hours per day outdoors had their probability of developing myopia reduced by 50% or more. If the outdoor time increased to 3 hours or more per day, the likelihood of developing myopia decreased

Table 5 Factors associated with 3-year progression of SE and elongation of AL among students at risk of myopia in the 3-year cohort study using linear regression (n=239)

	Progression of SE		Elongation of AL	
	Univariable model	Multivariable model	Univariable model	Multivariable model
Baseline characteristics	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Age at baseline (years)	0.016 (–0.324, 0.410)	–0.001 (–0.357, 0.353)	–0.080 (–0.208, 0.048)	–0.062 (–0.186, 0.061)
Sex, female	–0.019 (–0.332, 0.248)	0.074 (–0.145, 0.467)	0.028 (–0.078, 0.121)	–0.090 (–0.174, 0.034)
Time spent in self-study, more than 2 hours/day	–0.093 (–0.526, 0.091)	–0.075 (–0.479, 0.129)	0.061 (–0.056, 0.157)	0.042 (–0.069, 0.139)
Attending extra classes, yes	–0.082 (–0.761, 0.181)	–0.091 (–0.793, 0.143)	0.085 (–0.056, 0.278)	0.057 (–0.090, 0.239)
Studying on computer, yes	–0.140 (–0.597, –0.018)*	–0.184 (–0.699, –0.112)**	0.172 (0.035, 0.233)**	0.208 (0.062, 0.263)**
Daily time reading printed material indoors	–0.087 (–0.326, 0.068)	–0.085 (–0.319, 0.067)	0.073 (–0.029, 0.106)	0.070 (–0.029, 0.103)
Daily time playing video game indoors	–0.032 (–0.274, 0.167)	–0.033 (–0.270, 0.162)	0.037 (–0.054, 0.097)	0.038 (–0.051, 0.096)
Daily time watching TV indoors	–0.036 (–0.291, 0.166)	–0.101 (–0.403, 0.058)	0.048 (–0.049, 0.107)	0.086 (–0.026, 0.129)
Daily time playing sports indoors	–0.132 (–0.383, 0.000)	–0.163 (–0.432, –0.041)*	0.127 (0.000, 0.132)	0.155 (0.013, 0.147)*
Daily time playing/walking outdoors	0.073 (–0.089, 0.311)	0.017 (–0.188, 0.238)	–0.046 (–0.094, 0.044)	–0.028 (–0.087, 0.057)
Daily time playing sports outdoors	0.239 (0.146, 0.488)***	0.337 (0.254, 0.640)***	–0.194 (–0.151, –0.032)**	–0.289 (–0.202, –0.071)***
Baseline SE	0.006 (–0.299, 0.325)	–0.012 (–0.341, 0.284)	–0.158 (–0.239,–0.026)*	–0.160 (–0.239, –0.028)*
Baseline AL	–0.043 (–0.279, 0.144)	–0.018 (–0.245, 0.187)	0.060 (–0.038, 0.106)	0.010 (–0.067, 0.078)

*p < 0.05; **p < 0.01; ***p < 0.001.

by 40% or more.[29] This result was in line with our finding that performing outdoor activities was a protective factor, preventing the early onset of myopia and reducing the elongation of AL. Therefore, education on the protective effects of outdoor activities is important to change the lifestyle habits of students.

The present study found that using a computer for studying was associated with a greater progression of SE and elongation of AL. This finding aligns with that of earlier research that has reported a positive relationship between screen time and myopia, likely due to the increased near-work activities linked to prolonged use of electronic devices.[18 21 60–63] Yet, there is limited evidence to definitively establish computer use as a risk factor for myopia. Cross-sectional studies have presented conflicting results, and there is a scarcity of evidence from longitudinal studies. Notably, some cross-sectional studies did not find a significant association between computer use and myopia progression.[29 64] For example, a study from China found that activities such as watching television from 3 metres or less, reading from 20 centimeters or less and keeping a close distance between the eyes, nib and fingertips (2 centimeters or less) were significantly associated with the increased AL. However, using a computer and playing console games were not associated with AL elongation.[21] Additional findings from the Generation R cohort study in the Netherlands, which included 5074 children, suggested that computer use, particularly at a young age, had a moderate association with the onset of myopia during childhood.[60] Therefore, further research is needed to clarify the impacts of computer use and other modern digital products on myopia progression, especially among children and adolescents.

The strengths of our study are that we evaluated 3-year longitudinal data from 355 secondary school students had a high follow-up response rate and included data of both refractive error and AL. However, the present study had some limitations. First, noncycloplegic refraction was used in the present study. Noncycloplegic refraction overstates the prevalence of myopia in teenagers with active accommodation. However, we opted to use a robust threshold (−1.0 D instead of −0.5 D) for defining myopia to ensure greater accuracy in detecting true cases. In addition, children who were already myopic were excluded from studying the incidence of myopia. Second, the collection of risk and protective factors for myopia in this study relied on questionnaire completion by students, introducing the possibility of recall bias. Third, information about parental myopia and parental educational levels was not obtained. Therefore, their potential associations with children's myopia were not evaluated, although some studies addressed such relationships.[34 65 66] Fourth, the current study analysed a sample of 355 students. A larger sample size could improve the ability to detect certain associations or could reduce an overfitting of the data according to the adjustment for multiple covariates. Despite these limitations, the findings from this longitudinal cohort study provide valuable insights that contribute to the global understanding of myopia and its associated risk and protective factors.

In conclusion, this cohort study revealed a considerable incidence and progression of myopia among urban Vietnamese secondary school children and showed that more time spent on outdoor activities and less time spent on computer use were significantly associated with the incidence and progression of myopia. The results can aid in creating evidence-based public healthcare strategies and interventions aimed at addressing the increasing prevalence of myopia among secondary school students in urban areas of Vietnam. The results of this study may also have implications for other countries facing similar challenges related to myopia among adolescents. For instance, this finding may guide the implementation of school curricula that promote outdoor activities and judicious screen usage among students, which can help mitigate the burden of myopia-related visual impairment and associated health issues. Furthermore, these empirical data can assist eye-care professionals in anticipating the forthcoming requirements for refractive services, allocating resources accordingly and facilitating the development of screening initiatives and early intervention strategies to manage refractive errors and myopia among school students. Further research is required to explore the impact of near-work, particularly computer usage, and the influence of outdoor exposure on children's visual health. Informed programmes should be developed to preserve visual health and alleviate the burden of myopia on future generations.

Author affiliations
[1]Department of Global Health Entreprenership, Institute of Science Tokyo (Science Tokyo), Tokyo, Japan
[2]Faculty of Public Health, Hue University of Medicine and Pharmacy, Hue University, Hue City, Vietnam
[3]Institute for Community Health Research, Hue University of Medicine and Pharmacy, Hue University, Hue, Vietnam
[4]National Institute of Public Health, Japan, Wako, Japan
[5]Department of Ophtalmology and Visual Science, Institute of Science Tokyo (Science Tokyo), Tokyo, Japan
[6]Tokyo Metropolitan Hiroo Hospital, Tokyo, Japan

Acknowledgements The authors thank Prof. NVQH on overarching advice for the research and appreciate the support for data collection of the teams of the Faculty of Public Health and Department of Ophthalmology of Hue University of Medicine and Pharmacy. We also thank the Department of Education and Training in Thua Thien Hue Province, Vietnam, for granting permission for their schools to participate, the schools and teachers who kindly agreed to administer the survey and all students who generously completed the questionnaire.

Contributors Conceptualisation and design: XMTT, HTLN, KN and KS; Acquisition, analysis or interpretation of data: XMTT, HTLN, KN, KO-M, TI-Y and TVT; Drafting of the manuscript: XMTT; Critical revision of the manuscript for important intellectual content: HTLN, KN and KS; Supervision and guarantor: TVV, KO-M and TI-Y; Funding acquisition: KN. KN is the guarantor.

Funding Japanese Society for Promotion of Science (17H02164).

Competing interests None declared.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by the Institutional Review Board of the Medical School of Tokyo Medical and Dental University (M2017-176); Hue University of Medicine and Pharmacy (Jan6-2018). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer-reviewed.

Data availability statement Data are available upon reasonable request. The generated dataset is available upon request from the corresponding author at the indicated contact address.

ORCID iDs
Xuan Minh Tri Tran http://orcid.org/0000-0001-5418-1597
Hoang Thuy Linh Nguyen http://orcid.org/0000-0001-7231-9895
Thao Vi Tran http://orcid.org/0000-0001-8320-8015
Kaoruko Seino http://orcid.org/0000-0003-3145-6396
Kyoko Ohno-Matsui http://orcid.org/0000-0002-8375-6879
Tae Igarashi-Yokoi http://orcid.org/0000-0001-7360-1964
Keiko Nakamura http://orcid.org/0000-0002-9119-4730

REFERENCES

1 Sankaridurg P, Tahhan N, Kandel H, *et al*. IMI Impact of Myopia. *Invest Ophthalmol Vis Sci* 2021;62:2.
2 Chua SYL, Foster PJ. The economic and societal impact of myopia and high myopia. In: *Updates on myopia: a clinical perspective*. 2019: 55.
3 Bourne RRA, Stevens GA, White RA, *et al*. Causes of vision loss worldwide, 1990-2010: a systematic analysis. *Lancet Glob Health* 2013;1:e339–49.
4 Holden BA, Fricke TR, Wilson DA, *et al*. Global Prevalence of Myopia and High Myopia and Temporal Trends from 2000 through 2050. *Ophthalmology* 2016;123:1036–42.
5 Matsumura S, Ching-Yu C, Saw SM. Global epidemiology of myopia. In: *Updates on myopia: a clinical perspective*. 2019: 27–51.
6 Saw SM, Pan CW, Dirani M, *et al*. Is myopia more common in Asians? A systematic review and meta-analysis. *Invest Ophthalmol Vis Sci* 2014;55. Available: https://iovs.arvojournals.org/article.aspx?articleid=2269069
7 Spillmann L. Stopping the rise of myopia in Asia. *Graefes Arch Clin Exp Ophthalmol* 2020;258:943–59.
8 Morgan IG, Ohno-Matsui K, Saw SM. Myopia. *Lancet* 2012;379:1739–48.
9 Rim TH, Kim S-H, Lim KH, *et al*. Refractive Errors in Koreans: The Korea National Health and Nutrition Examination Survey 2008-2012. *Korean J Ophthalmol* 2016;30:214–24.
10 Wolffsohn JS, Flitcroft DI, Gifford KL, *et al*. IMI - Myopia Control Reports Overview and Introduction. *Invest Ophthalmol Vis Sci* 2019;60:M1–19.
11 Jonas JB, Ang M, Cho P, *et al*. IMI Prevention of Myopia and Its Progression. *Invest Ophthalmol Vis Sci* 2021;62:6.
12 Karuppiah V, Wong L, Tay V, *et al*. School-based programme to address childhood myopia in Singapore. *Singap Med J* 2021;62:63–8.
13 Ding B-Y, Shih Y-F, Lin LLK, *et al*. Myopia among schoolchildren in East Asia and Singapore. *Surv Ophthalmol* 2017;62:677–97.
14 Dirani M, Tong L, Gazzard G, *et al*. Outdoor activity and myopia in Singapore teenage children. *Br J Ophthalmol* 2009;93:997–1000.
15 Saw S-M, Tong L, Chua W-H, *et al*. Incidence and progression of myopia in Singaporean school children. *Invest Ophthalmol Vis Sci* 2005;46:51–7.
16 Tsai D-C, Fang S-Y, Huang N, *et al*. Myopia Development Among Young Schoolchildren: The Myopia Investigation Study in Taipei. *Invest Ophthalmol Vis Sci* 2016;57:6852–60.
17 Guo Y, Liu LJ, Tang P, *et al*. Outdoor activity and myopia progression in 4-year follow-up of Chinese primary school children: The Beijing Children Eye Study. *PLoS ONE* 2017;12:e0175921.
18 Huang HM, Chang DST, Wu PC. The Association between Near Work Activities and Myopia in Children-A Systematic Review and Meta-Analysis. *PLoS ONE* 2015;10:e0140419.
19 Guo Y, Liu LJ, Xu L, *et al*. Outdoor activity and myopia among primary students in rural and urban regions of Beijing. *Ophthalmology* 2013;120:277–83.
20 Jin J-X, Hua W-J, Jiang X, *et al*. Effect of outdoor activity on myopia onset and progression in school-aged children in northeast China: the Sujiatun Eye Care Study. *BMC Ophthalmol* 2015;15:73.
21 Li S-M, Li S-Y, Kang M-T, *et al*. Near Work Related Parameters and Myopia in Chinese Children: the Anyang Childhood Eye Study. *PLoS ONE* 2015;10:e0134514.
22 Pärssinen O, Kauppinen M. Risk factors for high myopia: a 22-year follow-up study from childhood to adulthood. *Acta Ophthalmol* 2019;97:510–8.
23 French AN, Morgan IG, Mitchell P, *et al*. Risk factors for incident myopia in Australian schoolchildren: the Sydney adolescent vascular and eye study. *Ophthalmology* 2013;120:2100–8.
24 Huang Z, Song D, Tian Z, *et al*. Prevalence and associated factors of myopia among adolescents aged 12-15 in Shandong Province, China: a cross-sectional study. *Sci Rep* 2024;14:17289.
25 Cheng H-C, Chang K, Shen E, *et al*. Risk Factors and Behaviours of Schoolchildren with Myopia in Taiwan. *Int J Environ Res Public Health* 2020;17:1967.
26 Chua SYL, Ikram MK, Tan CS, *et al*. Relative Contribution of Risk Factors for Early-Onset Myopia in Young Asian Children. *Invest Ophthalmol Vis Sci* 2015;56:8101–7.
27 Paudel P, Ramson P, Naduvilath T, *et al*. Prevalence of vision impairment and refractive error in school children in Ba Ria - Vung Tau province, Vietnam. *Clin Exp Ophthalmol* 2014;42:217–26.
28 Limburg H, Gilbert C, Hon DN, *et al*. Prevalence and causes of blindness in children in Vietnam. *Ophthalmology* 2012;119:355–61.
29 Hung HD, Chinh DD, Tan PV, *et al*. The Prevalence of Myopia and Factors Associated with It Among Secondary School Children in Rural Vietnam. *Clin Ophthalmol* 2020;14:1079–90.
30 Government of Vietnam. Decision to approve the National Plan for blindness prevention and eye care towards 2020 and vision 2030. 2016.
31 Noncommunicable disease surveillance, monitoring and reporting, GSHS questionnaire. World Health Organization.
32 Luo F, Hao J, Li L, *et al*. Baseline Refractive Error, Habitual Accommodative Tone, and Its Association With Myopia in Children: The Lhasa Childhood Eye Study. *Invest Ophthalmol Vis Sci* 2023;64:4.
33 Guggenheim JA, Northstone K, McMahon G, *et al*. Time outdoors and physical activity as predictors of incident myopia in childhood: a prospective cohort study. *Invest Ophthalmol Vis Sci* 2012;53:2856–65.
34 Jiang D, Lin H, Li C, *et al*. Longitudinal association between myopia and parental myopia and outdoor time among students in Wenzhou: a 2.5-year longitudinal cohort study. *BMC Ophthalmol* 2021;21:11.
35 Flitcroft DI, He M, Jonas JB, *et al*. IMI - Defining and Classifying Myopia: A Proposed Set of Standards for Clinical and Epidemiologic Studies. *Invest Ophthalmol Vis Sci* 2019;60:M20–30.
36 Ramamurthy D, Lin Chua SY, Saw SM. A review of environmental risk factors for myopia during early life, childhood and adolescence. *Clin Exp Optom* 2015;98:497–506.
37 Xie Z, Long Y, Wang J, *et al*. Prevalence of myopia and associated risk factors among primary students in Chongqing: multilevel modeling. *BMC Ophthalmol* 2020;20:146.
38 Singh NK, James RM, Yadav A, *et al*. Prevalence of Myopia and Associated Risk Factors in Schoolchildren in North India. *Optom Vis Sci* 2019;96:200–5.
39 Harrington SC, Stack J, O'Dwyer V. Risk factors associated with myopia in schoolchildren in Ireland. *Br J Ophthalmol* 2019;103:1803–9.
40 Ha T, Harpham T. Primary Education in Vietnam: Extra Classes and Outcomes. *Int Educ j* 2005.
41 Li S-M, Li H, Li S-Y, *et al*. Time Outdoors and Myopia Progression Over 2 Years in Chinese Children: The Anyang Childhood Eye Study. *Invest Ophthalmol Vis Sci* 2015;56:4734–40.
42 Hsu C-C, Huang N, Lin P-Y, *et al*. Risk factors for myopia progression in second-grade primary school children in Taipei: a population-based cohort study. *Br J Ophthalmol* 2017;101:1611–7.
43 Lin Z, Vasudevan B, Gao T, *et al*. Refractive change and incidence of myopia among rural Chinese children: the Handan Offspring Myopia Study. *Br J Ophthalmol* 2022;106:628–32.
44 Bikbov MM, Kazakbaeva GM, Fakhretdinova AA, *et al*. Myopic axial elongation in school children and the COVID-19 lockdown in Russia: The Ural Children Myopia Study. *PLoS ONE* 2023;18:e0279020.
45 Li L, Zhong H, Li J, *et al*. Incidence of myopia and biometric characteristics of premyopic eyes among Chinese children and adolescents. *BMC Ophthalmol* 2018;18:178:178:.
46 Wang SK, Guo Y, Liao C, *et al*. Incidence of and Factors Associated With Myopia and High Myopia in Chinese Children, Based on Refraction Without Cycloplegia. *JAMA Ophthalmol* 2018;136:1017–24.

47 Saxena R, Vashist P, Tandon R, *et al*. Incidence and progression of myopia and associated factors in urban school children in Delhi: The North India Myopia Study (NIM Study). *PLoS ONE* 2017;12:e0189774.
48 Fortin P, Kwan J. The Myopia Management Opportunity in the United States Using the 2020 Census. *Invest Ophthalmol Vis Sci* 2022;63:244–A0098. Available: https://iovs.arvojournals.org/article.aspx?articleid=2779140
49 Kneepkens S, Tideman JW, Polling JR, *et al*. Prevalence of myopia in the current young generation in the Netherlands. *Invest Ophthalmol Vis Sci* 2023;64:805. Available: https://iovs.arvojournals.org/article.aspx?articleid=2786140
50 Ma Y, Zou H, Lin S, *et al*. Cohort study with 4-year follow-up of myopia and refractive parameters in primary schoolchildren in Baoshan District, Shanghai. *Clin Exp Ophthalmol* 2018;46:861–72.
51 French AN, Ashby RS, Morgan IG, *et al*. Time outdoors and the prevention of myopia. *Exp Eye Res* 2013;114:58–68.
52 Deng L, Pang Y. Effect of Outdoor Activities in Myopia Control: Meta-analysis of Clinical Studies. *Optom Vis Sci* 2019;96:276–82.
53 Xiong S, Sankaridurg P, Naduvilath T, *et al*. Time spent in outdoor activities in relation to myopia prevention and control: a meta-analysis and systematic review. *Acta Ophthalmol* 2017;95:551–66.
54 Rose KA, Morgan IG, Smith W, *et al*. Myopia, lifestyle, and schooling in students of Chinese ethnicity in Singapore and Sydney. *Arch Ophthalmol* 2008;126:527–30.
55 Rose KA, Ip J, Robaei D, *et al*. Near–Work and Outdoor Activities and the Prevalence of Myopia in Australian School Students Aged 12–13 Years: The Sydney Myopia Study. *Invest Ophthalmol Vis Sci* 2006;47. Available: https://iovs.arvojournals.org/article.aspx?articleid=2395238
56 Mukazhanova A, Aldasheva N, Iskakbayeva J, *et al*. Prevalence of refractive errors and risk factors for myopia among schoolchildren of Almaty, Kazakhstan: A cross-sectional study. *PLoS ONE* 2022;17:e0269474.
57 He M, Xiang F, Zeng Y, *et al*. Effect of Time Spent Outdoors at School on the Development of Myopia Among Children in China: A Randomized Clinical Trial. *JAMA* 2015;314:1142–8.
58 Guan H, Yu NN, Wang H, *et al*. Impact of various types of near work and time spent outdoors at different times of day on visual acuity and refractive error among Chinese school-going children. *PLoS ONE* 2019;14:e0215827.
59 Wu P-C, Chen C-T, Chang L-C, *et al*. Increased Time Outdoors Is Followed by Reversal of the Long-Term Trend to Reduced Visual Acuity in Taiwan Primary School Students. *Ophthalmology* 2020;127:1462–9.
60 Enthoven CA, Tideman JWL, Polling JR, *et al*. The impact of computer use on myopia development in childhood: The Generation R study. *Prev Med* 2020;132:105988.
61 Saxena R, Gupta V, Prasad P, *et al*. Prevalence of myopia and its risk factors in rural school children in North India: the North India myopia rural study (NIM-R Study). *Eye (Lond)* 2022;36:2000–5.
62 Fernández-Montero A, Olmo-Jimenez JM, Olmo N, *et al*. The impact of computer use in myopia progression: a cohort study in Spain. *Prev Med* 2015;71:67–71.
63 Foreman J, Salim AT, Praveen A, *et al*. Association between digital smart device use and myopia: a systematic review and meta-analysis. *Lancet Digit Health* 2021;3:e806–18.
64 Lu B, Congdon N, Liu X, *et al*. Associations between near work, outdoor activity, and myopia among adolescent students in rural China: the Xichang Pediatric Refractive Error Study report no. 2. *Arch Ophthalmol* 2009;127:769–75.
65 Lim DH, Han J, Chung T-Y, *et al*. The high prevalence of myopia in Korean children with influence of parental refractive errors: The 2008-2012 Korean National Health and Nutrition Examination Survey. *PLoS ONE* 2018;13:e0207690.
66 Pärssinen O, Kauppinen M. What is the influence of parents' myopia on their children's myopic progression? A 22-year follow-up study. *Acta Ophthalmol* 2016;94:579–85.