International Journal of Nursing and Health Care Research

Shen Y, et al. Int J Nurs Health Care Res 9: 1713

www.doi.org/10.29011/2688-9501.101713

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Research Article

Myopia Progression and its Risk Factors among Fourth-Grade Children in Zhejiang, China: a Two-Year Prospective Cohort Study

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Citation: Shen Y, Li J, Jia M, Gu F, Zhao D, et al. (2026) Myopia Progression and its Risk Factors among Fourth-Grade Children in Zhejiang, China: a Two-Year Prospective Cohort Study. Int J Nurs Health Care Res 9:1713. DOI: https://doi.org/10.29011/2688-9501.101713

Received Date: 24 June 2026; **Accepted Date:** 07 July 2026; **Published Date**: 10 July, 2026

Abstract

Background: Myopia has become a major public-health challenge among East-Asian children. The primary-school years, especially Grades 4-5, are now recognized as a critical window for both onset and rapid progression; however, the combined influence of genetic and environmental risk factors during this period remains incompletely quantified. **Methods:** We conducted a population-based, two-year prospective cohort study in Zhejiang Province, China. In September 2023 (Grade 4, mean age 9.36 y) and September 2024 (Grade 5) we examined 7115 pupils, matched by school, class, name and date of birth. Annual refractive change was calculated from non-cycloplegic autorefraction; myopia was defined as spherical equivalent ≤ –0.50 D with uncorrected distance visual-acuity < 5.0. Progression patterns were classified as stable, slow, moderate or rapid (≤ –1.00 D/year). Risk factors (sex, parental myopia, baseline refraction, near-work, outdoor time, sleep duration) were collected by validated questionnaires. Multiple linear and multinomial logistic regression analyses were performed. **Results:** Median annual refractive change was –0.38 D. Myopia prevalence rose from 39.38 % to 53.89 % ($p < 0.001$). Female sex (β= –0.186 D, $P < 0.001$), higher baseline myopia (β= –1.000, $P < 0.001$) and two myopic parents (β=–0.352, $P < 0.001$) independently predicted greater annual progression. In multinomial models, female students (rapid vs stable: OR=1.58, 95% CI=1.38–1.80) and those with two myopic parents (rapid: OR=1.18, 95% CI=1.08–1.28) were at highest risk, whereas ≥ 3 h/day outdoor activity (moderate: OR=0.73; rapid: OR=0.69) and longer nightly sleep (rapid: OR= 0.93) were protective. **Conclusion:** Grade 4-5 represents a pivotal period for escalating myopia. Sex, baseline refraction, parental myopia, insufficient outdoor exposure and short sleep jointly determine progression trajectory. Targeted surveillance and integrated behavioural interventions-especially for girls and children with myopic parents-should be implemented to mitigate future high-myopia burdens.

Keywords: Myopia progression; Primary school; Outdoor activity; Sex differences; Parental myopia

Introduction

In recent years, the prevalence of myopia among children and adolescents has become a pressing public health issue globally, with particularly alarming rates in East Asia, including China. East and Southeast Asian countries report the highest prevalence rates among schoolchildren, for example, 47.4% in China [1], 64% in Japan [2] and 48.2% in Korea [3]. South Asians have a much lower rate, such as India (13.1%) [4], black Africans have the lowest prevalence (7%) [5], and white Europeans have inter mediate prevalence, such as Netherland (2.4%) [6], France (42.7%) [7], and Denmark (17.9%) [8]. The prevalence of myopia in South Asians and minimal change in the prevalence of myopia in whites. It is expected that by 2050, the global myopia population will reach 4.76 billion, and the population with high myopia will reach 938 million, accounting for nearly 50% and 10% of the world's population, respectively [9].

Myopia results from various influences, both genetic and environmental. A wealth of research has identified several key contributors to the development and worsening of myopia, including near work, outdoors time, heavy electronic device usage, and parental myopia [10,11]. Other factors still need to be further confirmed by cohort studies. At present, the mechanisms behind the progression of myopia and the factors influencing it are not yet fully understood. The advancement of axial myopia relies on the elongation of the eye's axis [11], and since this elongation is a common basis for both the onset and progression of myopia, the progression should also be influenced by the amount of time spent on outdoor activities. An intervention study in Taiwan showed that there was no significant relationship between outdoor activity and myopic shift [12]. However, a cohort study in Henan province of China showed that outdoor activities had protective effect on myopic progression among grade7 school children [13]. A Meta analyses in 2025 assumed higher outdoor exposure appeared more effective in reducing myopia progression, but the certainty of this evidence was rated as low due to suspected publication bias [14]. Therefore, we need to explore new methods to reduce the influence of confounders, identify covariates, and measure the magnitude and importance of interactions between variables.

In this study, we conducted eye examinations and questionnaires on related factors for primary school students in grades 4 in Zhejiang Province, China, for 2 consecutive years (2023-2024), aiming to explore risk factors affecting myopia progression. This study will provide a reference for the development of myopia prevention and control strategies for adolescents.

Methods

Study Population

A population-based and cross-sectional study was conducted in September 2023, and again in September 2024. Randomized stratified whole cluster sampling was used in this study. Zhejiang Province has 11 prefecture-level cities. We randomly selected on urban area and on suburban county from each prefecture-level city, with two primary schools from the urban area and two from the suburban county, respectively. Investigations were conducted on whole classes at 4th-5th grade level in primary schools, with at least 80 students selected from each grade. The data of 4th-grade students from survey in 2023 with the 5th-grade students from survey in 2024 were matched by school, class, name, and date of birth. A total of 7115 students were confirmed to be recruited in the investigation over consecutive years.

Informed consent was obtained from all participants. The study was approved by the ethics committee of Zhejiang Provincial Center for Disease Control and Prevention and followed the tenets of the Declaration of Helsinki.

Ocular Measurements

Ocular measurements included distance vision examinations and refraction tests. The staff consisted of at least one specialist ophthalmologist and several technicians or nurses in specialist areas. All testers were trained to be proficient in the testing methods and could only start work after passing the test. Uncorrected distance visual acuity (UDVA) was uniformly performed using a standard logarithmic visual acuity E-chart, and the test results were recorded using the five-point recording method. Non-cycloplegic autorefraction examinations were conducted using Topcon RM-800 computer optometry (Topcon Co., Japan) to read the values of spherical lenses, cylinder, and axial length. Spherical equivalent (SE) was calculated as spherical lenses plus 1/2 cylinder. Myopia was defined as UDVA < 5.0 and SE < -0.50D. Subjects wearing keratoconus lenses or using low-concentration atropine eye drops were excluded.

The annual refractive change was defined as the total refractive change, with negative values indicating myopia progression. According to annual rate of refractive error progression, the patterns of refraction development are categorized as follows: **(1)** Rapid progression pattern: ≤-1.00 diopters (D) per year; **(2)** Moderate progression pattern: ≤-0.50 D/year and >-1.00 D/year; **(3)** Slow progression pattern: ≤-0.25 D/year and >-0.50 D/year**;** **(4)** Stable pattern: >-0.25 D/year [15].

Questionnaire Study

Self-administered questionnaires, including students' basic information, myopia-related reading and writing postures, and behavioural habits, were used in 2023. After the unified training, investigators sent questionnaires to schools, asked the students to fill in, and requested the teachers to collect them back. After collecting and reviewing the questionnaires, in case of incomplete and illogical questionnaires, investigators contacted the respondent to explain it and refill the questionnaire.

Statistical Analysis

The data were analyzed using the SE for the worst eye of each student. A database was created using Epi Data 3.1, and after data were entered in a double-blind manner and checked for errors, the data were analyzed using the R software (version 4.0.3, https://www.r-project.org/). Descriptive statistics were expressed as the mean ± standard deviation (mean ± SD) for continuous variables and as the rate (%) for categorical variables. Non-normal continuous variables are expressed in the form of quartiles. Paired t-test was conducted to compare SE in two consecutive years, and paired chi-squared test was applied for myopia rate comparation. Multifactor linear regression was used to analyze the relationship between individual baseline characteristics and environmental factors and changes in students' SE change. To determine the associations between influencing factors and refraction progression patterns, logistic regression analysis was applied to compare slow, moderate and rapid pattern with stable pattern. Due to the similar results between the baseline and the final refraction for the right eye and the left eye, this study only presents the data of regression models for the right eye, and results for the left eye was presented as supplementary tables for sensitivity analysis. A p-value <0.05 was considered to be statistically significant.

	Spherical Equivalent Refraction (quantile)			
	Left			
	2023	2024	t	P
Total	-0.38(-1.38,0.13)	-0.75(-2.00,0.00)	-3.835	<0.001
Male	-0.25(-1.25,0.13)	-0.63(-1.88, 0.00)	2.189	0.029
Female	-0.50(-1.50,0.13)	-0.88(-2.12, -0.01)	3.158	0.002

Supplementary 1: Refractive status of left eye from 2023 to 2024

Variable	Annual refractive change	
	Left eye	
	ß(SE)	P
Female	-0.181(0.038)	<0.001
Baseline refraction	-0.999(0.000)	<0.001
Number of myopic parents	-0.348(0.026)	<0.001
Duration of reading and writing each day		
<1h	ref	-
1~2h	0.047(0.044)	0.284
2~3h	0.013(0.063)	0.842
≥3h	0.074(0.067)	0.268
Duration of outdoor activity each day		
<1h	ref	-
1~2h	0.100(0.045)	0.026
2~3h	0.244(0.059)	<0.001
≥3h	0.225(0.086)	0.009
Unknown	0.181(0.148)	0.222
Duration of electronic devices each day		
<1h	ref	-
1~2h	0.003(0.044)	0.952
2~3h	0.029(0.062)	0.635
≥3h	-0.079(0.080)	0.326
never	ref	-
<1 /day	-0.050(0.042)	0.229
≥1 /day	0.003(0.102)	0.974
Whether to check vision every one year		
0	ref	-
1	-0.083(0.091)	0.364
2	-0.193(0.087)	0.027
≥3	-0.427(0.091)	<0.001
Sleeping hour, hour	0.009(0.018)	0.596

Supplementary 2: Multivariate regression analysis of factors on refractive change.

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Variable	Myopic shift			
	Left			
	Stable	Slow	Moderate	Rapid
Female	ref	0.93(0.81-1.07)	1.17(1.04-1.32	1.41(1.24-1.61)
Baseline refraction	ref	1.00(0.99-1.01)	0.94(0.90-1.07)	1.00(0.99-1.01)
Number of myopic parents	ref	0.97(0.88-1.06)	1.08(0.99-1.18)	1.12(1.02-1.22)
Duration of outdoor activity each day				
<1h	ref	-	-	-
1~2h	ref	1.03(0.88-1.22)	0.89(0.77-1.02)	0.88(0.75-1.02)
2~3h	ref	0.82(0.66-1.02)	0.73(0.61-0.88)	0.74(0.61-0.91)
≥3h	ref	0.69(0.49-0.96)	0.74(0.57-0.97)	0.69(0.51-0.93)
Duration of reading and writing each day				
<1h	ref	-	-	-
1~2h	ref	0.89(0.76-1.04)	1.01(0.82-1.08)	0.85(0.74-0.99))
2~3h	ref	0.94(0.80-1.26)	1.03(0.84-1.25)	0.97(0.90-1.37)
≥3h	ref	0.90(0.61-1.02)	1.11(0.78-1.19)	0.98(0.78-1.23)
Unknown	ref	1.23(0.75-2.04)	0.84(0.52-1.36)	0.75(0.44-1.27)
Duration of electronic devices each day				
<1h	ref	-	-	-
1~2h	ref	1.04(0.89-1.22)	1.03(0.89-1.18)	0.95(0.82-1.11)
2~3h	ref	0.89(0.71-1.11)	0.90(0.74-1.10)	0.94(0.76-1.16)
≥3h	ref	0.93(0.69-1.26)	1.06(0.83-1.37)	1.14(0.87-1.49)
Frequency of eating sweets or carbonated beverages				
never	ref	-	-	-
<1 /day	ref	0.96(0.82-1.12)	1.07(0.94-1.22)	1.05(0.91-1.21)
≥1 /day	ref	0.93(0.64-1.35)	0.99(0.72-1.37)	0.98(0.69-1.39)
Whether to check vision every one year				
0	ref	-	-	-
1	ref	1.13(0.81-1.56)	1.32(0.98-1.77)	1.10(0.81-1.50)
2	ref	1.16(0.85-1.59)	1.32(0.99-1.75)	1.13(0.84-1.52)
≥3	ref	1.12(0.81-1.56)	1.30(0.97-1.75)	1.25(0.92-1.71)

Sleeping hour, hour	ref	1.02(0.96-1.09)	0.99(0.94-1.05)	1.00(0.94-1.06)

Supplementary 3: Multivariate logistic regression analysis of factors on myopic shift.

Results

The main characteristics of the study participants are reported in Table 1. Of the 7115 Grade 4 school students, the mean age in the 2023 baseline survey was 9.36±0.49 years. The proportion of male students in the three groups was 52.49%. The situation of parental myopia and frequency of reading, outdoor activity and electronic device usage were also shown in Table 1.

Variable	All
Number	7115
Baseline age	9.36±0.49
Male (%)	3735(52.49)
Parental myopia	
Father	1037(14.57)
Mother	1599(22.47)
Both	1317(18.51)
None	3162(44.44)
Duration of reading and writing each day	
<1h	2168(30.47)
1~2h	3248(45.65)
2~3h	1166(16.39)
≥3h	410(5.76)
Unknown	123(1.73)
Duration of electronic devices	
<1h	3741(52.58)
1~2h	2072(29.14)
2~3h	842(11.83)
≥3h	459(6.45)
Duration of outdoor activity each day	
<1h	2413(33.91)
1~2h	3044(42.78)
2~3h	897(12.61)
≥3h	761(10.70)
Whether to rest after a period of continuous reading	
≤15min	1512(21.25)
15min-0.5h	2016(28.33)
0.5-1h	2176(30.58)
>1h	1411(19.83)

Table 1: Baseline characteristics of the study participants.

The median equivalent spherical lenses were -0.38(-1.38,0.13) D in Grade 4 and -0.75(-2.00, -0.13) D in Grade 5, respectively. The difference between the two groups was statistically significant (t=-3.886, P<0.001). Among male students, the SE in Grade 4 and Grade 5 were -0.38 (-1.31, 0.13) and -0.69 (-1.88, 0.00), respectively, with a statistically significant difference between the two years (t=2.235, P<0.001). A similar trend was found among males (-0.38(-1.31, 0.13) vs. -0.69(-1.88, 0.00), t=-15.818, P<0.001) and females (-0.50(-1.50,0.00) vs. -0.93(-2.13, -0.13), t=3.189, P<0.001). (Figure 1a). The myopic rates significantly increased from 2023 (39.38%) to 2024 (52.89%) (χ^2=589.64, P<0.001). The myopia rate progression was also existed among male (37.02% vs. 48.38%, χ^2=231.77, P<0.001) and female students (41.99% vs. 57.87%, χ^2=363.21, P<0.001) (Figure 2b).

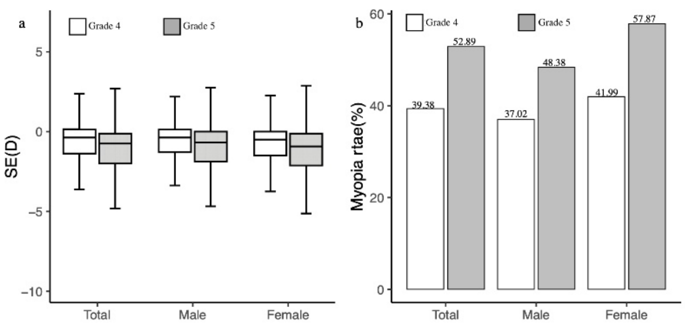

Figure 1: Refractive status of right eye (a) and prevalence of myopia (b) from grade 4 to grade 5.

There were significant differences in the annual refractive change among students with different refractive statuses. Multiple linear regression analyses were performed with annual refractive change as the dependent variable and 9 risk factors of myopia progression as the independent variables (Table 2). The results revealed that female (ß(SE)=-0.186(0.037), P <0.001), higher baseline refraction (ß(SE)=-1.000(0.000), P <0.001), more parents with myopia (ß(SE)= -0.352(0.025), P <0.001) will show more decreased myopic refractive change, and increased outdoor activity duration was associated with increased refractive change (1~2h: ß(SE)=0.094(0.044), P=0.032; 2~3h: 0.244(0.057), <0.001; ≥3h: 0.264(0.084), 0.002).

Variable	Annual refractive change	
	ß(SE)	P
Female	-0.186(0.037)	<0.001
Baseline refraction	-1.000(0.000)	<0.001
Number of myopic parents	-0.352(0.025)	<0.001
Duration of reading and writing each day		
<1h	ref	-
1~2h	0.049(0.043)	0.255
2~3h	0.047(0.062)	0.45
≥3h	0.105(0.066)	0.111
Duration of outdoor activity each day		
<1h	ref	-
1~2h	0.094(0.044)	0.032
2~3h	0.244(0.057)	<0.001
≥3h	0.264(0.084)	0.002
Unknown	0.211(0.146)	0.152
Duration of electronic devices each day		
<1h	ref	-
1~2h	0.026(0.043)	0.543
2~3h	0.053(0.061)	0.378
≥3h	-0.057(0.078)	0.467
Frequency of eating sweets or carbonated beverages		
never	ref	-
<1 /day	-0.037(0.041)	0.372
≥1 /day	-0.109(0.100)	0.275
Sleeping hour, hour	0.021(0.018)	0.242

Table 2: Multivariate regression analysis of factors on refractive change.

Multiple logistic regression analyses were conducted, utilizing refractive development pattern as the dependent variable and 9 risk factors as the independent variables (Table 3). Female (moderate: OR (95%CI) =1.23(1.09-1.39), P<0.001; rapid: 1.58(1.38-1.80), <0.001) and more parents with myopia (rapid: 1.18(1.08-1.28), <0.001) were risks factors for refraction development progression, while increased outdoor activity duration (moderate: ≥3h: 0.73(0.55-0.97), 0.024; rapid: 2~3h: 0.75(0.62-0.92), 0.003; ≥3h: 0.69(0.51-0.93), 0.009) and sleeping hour (rapid: 0.93(0.88-0.99), 0.030) were protective factor.

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Variable	Patterns of refraction development						
	Stable	Slow		Moderate		Rapid	
		OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
Female	ref	1.07(0.93-1.23)	0.32	1.23(1.09-1.39)	<0.001	1.58(1.38-1.80)	<0.001
Baseline refraction	ref	1.02(0.98-1.06)	0.412	0.98(0.94-1.02)	0.329	1.02(0.98-1.06)	0.335
Number of myopic parents	ref	1.06(0.97-1.17)	0.224	1.07(0.98-1.16)	0.134	1.18(1.08-1.28)	<0.001
Duration of outdoor activity each day							
<1h	ref	-		-		-	
1~2h	ref	1.00(0.85-1.18)	0.959	1.05(0.91-1.21)	0.52	0.90(0.77-1.05)	0.149
2~3h	ref	0.93(0.75-1.15)	0.417	0.84(0.70-1.01)	0.06	0.75(0.62-0.92)	0.003
≥3h	ref	1.09(0.81-1.46)	0.673	0.73(0.55-0.97)	0.024	0.69(0.51-0.93)	0.009
Duration of reading and writing each day							
<1h	ref	-		-		-	
1~2h	ref	1.01(0.86-1.19)	0.846	0.98(0.85-1.12)	0.803	0.79(0.78-1.05)	0.053
2~3h	ref	1.10(0.88-1.38)	0.339	0.88(0.72-1.08)	0.263	0.96(0.78-1.19)	0.871
≥3h	ref	0.93(0.72-1.18)	0.608	0.86(0.69-1.06)	0.173	0.89(0.71-1.11)	0.373
Unknown	ref	1.03(0.60-1.77)	0.934	1.21(0.77-1.90)	0.404	0.69(0.40-1.19)	0.181
Duration of electronic devices each day							
<1h	ref	-		-		-	
1~2h	ref	1.00(0.85-1.18)	0.987	0.95(0.83-1.09)	0.458	1.01(0.87-1.17)	0.97
2~3h	ref	0.97(0.78-1.21)	0.77	0.90(0.74-1.10)	0.313	0.95(0.77-1.18)	0.61
≥3h	ref	0.88(0.66-1.19)	0.392	0.82(0.63-1.06)	0.121	1.07(0.82-1.40)	0.667
Frequency of eating sweets or carbonated beverages							
never	ref	-		-		-	
<1 /day	ref	0.95(0.81-1.10)	0.459	0.98(0.86-1.12)	0.781	1.02(0.89-1.18)	0.791
≥1 /day	ref	1.19(0.83-1.71)	0.385	1.09(0.78-1.52)	0.638	1.32(0.94-1.86)	0.137
Sleeping hour, hour	ref	0.95(0.89-1.01)	0.109	0.98(0.92-1.03)	0.406	0.93(0.88-0.99)	0.03

Table 3: Multivariate logistic regression analysis of factors on patterns of refraction development.

Discussion

The progression of myopia involves a gradual increase in spherical equivalent refraction. Slowing this progression in myopic students is significant, as it helps prevent the onset of high myopia and reduces associated risks of visual impairment and blindness caused by high myopia complications. Similar to the development of myopia, its progression is driven by a multifactorial process in which genetic and environmental factors act both independently and interactively. This study investigated the association between genetic and environmental factors and annual refraction change, which control of myopia progression.

The present study exhibited a significant decrease in the refraction and an increase in the myopia rate over one year among Grade 4 primary school students. Due to escalating academic demands and the onset of puberty, the 4th grade of primary school constitutes a critical period of myopia onset and progression [16-19]. The mean age of this study was 9.36 years old, and the mean annual refractive progression was -0.38D. Among the surveyed students, the myopia rate was 39.38% in Grade 4 and increased to 53.89% in Grade 5, which showed a sharp upward trend from Grade 4 to Grade 5. In a study from UK, the mean refractive progression was -0.40 (-0.19 to -0.74) D/year among children aged 5.4 years, the proportion of myopia increased from 24% to 32% [20]. In China, a cohort study from Shanxi Province, the mean refractive change increased to -1.32±0.65 D over 24 months of follow-up among students aged between 6 and 14 years [21]. In a cohort study in Jiangsu Province, the median refractive error values for non-myopic boys were 0.0 at ages 6 and 7 years, decreasing to −0.13 D at ages 8 and 9 years [22]. The myopia rate gradually escalated from 23.4% in Grade 1 to 80.1% in Grade 5. Another cohort study based on a 5-year follow-up in Jiangsu revealed that the myopia rate gradually escalated from 23.4% in Grade 1 to 80.1% in Grade 5 of primary school students [23]. Our data was consistent with the above studies. The primary school stage is a critical period for the rise in myopia rates and refractive progression, especially in Grade 4 and Grade 5. The results suggested the refractive status of students during this stage should be a concern, particularly in controlling risk factors.

Refractive progression is also influenced by both genetic and environmental factors. A cohort study in Hubei Province of China demonstrated that risk factors for myopia progression included higher baseline refractive error, elevated body mass index, and frequent consumption of sweets, whereas parental supervision and strong eye-care awareness were protective factors [24]. Near-work activity represents an additional risk factor for myopia. A large amount of time spent reading, studying, and working on digital devices increases the risk for myopia by imposing sustained accommodative demand [25]. Another longitudinal study in Shanxi Province of China revealed that shorter distances of screens were directly related to myopic progression [21]. Our results showed that the mount of myopia progression varies by sex, parental myopia and baseline refraction. Female students had higher decreased annual refractive change. Which was in line with the higher myopia incidence among girls [26,27].

In our study, annual refractive change was faster for females than males (ß(SE)=-0.186(0.037), P <0.001). This difference has also been observed in India [28] and France [29]. This might be explained by the faster maturation and body growth in girls at this age [30]. Genetics is another influencing factor associated with myopia. A Meta analyses suggested that children whose parents had myopia were more likely to develop myopia [27]. A cohort study for in Anyang Province of China revealed that the incidence of myopia was higher in schoolchildren of Grade 1 with two myopic parents after follow ups for 5 years (OR (95%CI) =2.85 (1.76, 4.6)) [19]. In our results, the number of myopic parents is significantly associated with the progression of annual refractive progression, which demonstrated that refractive status of children with myopic parents should be more concerned compared those without myopic parents.

The French study revealed that higher refraction at baseline was associated with faster myopia progression (at least –0.33 D for SE ≤ –1 D) [29]. The retrospective study in UK revealed that progression was faster in initial moderate than initial mild myopia (−0.54 vs −0.37 D/year; p<0.001) among children with 5.4 years [20]. Our results also revealed that higher refraction at baseline was significantly associated with decreased annual refractive change (ß(SE)= -1.000(0.000), P<0.001). It is possible that once refractive status has reached a certain level, myopia is more likely to increase further through biomechanical alterations in the scleral extracellular matrix [31].

It is generally considered that outdoor time and daylight were protective factors for myopia onset. The association between outdoor activity and myopia progression remained conflict.

The longitudinal study in Shanxi Province of China exhibited that increased time of outdoor activity inversely related to myopic progression [21]. Besides International Myopia Institute (IMI) recommends ≥2 hours of daily outdoor time for preventing myopia onset and progression [32]. However, some studies reported that increased outdoor time had a limited effect on myopia progression. For example, a cohort study in Taipei reported that time spent in outdoor activities after school on weekdays (reference ≥1hour/day) or weekends (reference ≥2hours/day) was not associated with slowed myopia SE progression [33]. Another study among studies during puberty (mean age = 10.9 ± 1.5 years) in Turkey showed that outdoor activities had no correlations with annual myopia progression rate [34]. In our study, increased outdoor time was statistically significantly associated with annual refraction change (reference <1hour/day) and exhibited a dose-response relationship.

More increased outdoor time had better protective effect against myopia progression when duration of outdoor activity reached ≥3h/day (1~2h/day: ß(SE)=0.094(0.044), P=0.032; 2~3h/day: 0.244(0.057), <0.001; ≥3h/day: 0.264(0.084), 0.002). This protective effect may be due to high light intensity outdoors, the chromaticity of daylight or increased vitamin D levels [35]. It could also be supposed that higher myopia incidence and progression among girls because they had slightly more nearby work activities or spent less outdoor time than boys, but this still remains speculative.

In our study, we categorized refractive progression patterns as rapid (≤-1.00 D/year), moderate (≤-0.50 D/year and >-1.00 D/year), slow (≤-0.25 D/year and >-0.50 D/year) and stable (>-0.25 D/year). When evaluating the risk factors of refractive progression patterns, we found that, compared with stable pattern, moderate and rapid pattern were associated with female, which was consistent with the trend of annual refraction change. Rapid pattern was associated with increased numbers of myopic parents, which indicated that parents with myopia should be particularly awareness with their children's myopic progression. More than 3 hours of daily outdoor exposure was associated with moderate progression pattern (OR (95%CI) = 0.73(0.55-0.97)) and rapid pattern (0.69(0.51-0.93)), while 2-3 hours was only associated with rapid pattern (0.75(0.62-0.92)).

Our study results implicate that adequate daily outdoor activity duration might be helpful in decreasing the speed of refractive progression in young children. Besides, we found that increased sleeping hour was reversely associated with rapid refractive progression (OR (95%CI) = 0.93(0.88-0.99)). It suggested that sufficient sleep may serve as a simple yet effective adjunctive strategy to curb accelerated refractive progression during childhood. Therefore, for Grade 4 primary schoolchildren, girls and children with two myopic parents should be concerned about rapid myopia progression. In addition, adequate outdoor and sleeping duration were protective factor for rapid pattern.

This study has several strengths. First, the sample size is relatively large. Second, we employed patterns of refraction development to quantify the rate of refractive change. These data facilitated us to comprehensively assess the risk factors associated with myopia progression in such a young population.

The limitations of this study are as follows. First, the 1-year follow-up period is short, and studies with longer follow-up are warranted. Second, non-cycloplegic measurements of myopia were used, and the prevalence of myopia may have been overestimated. Third, recall bias may have arisen from the use of self-reported questionnaire data.

Conclusion

Female sex, higher baseline refraction, and having two myopic parents as robust predictors of refraction shift and rapid or moderate progression patterns. Conversely, daily outdoor exposure ≥ 3 h were independently protective, demonstrating clear dose–response relationships. Integrating sex-specific surveillance, family-based screening, and behaviour interventions into school health programs could substantially curb the trajectory toward high myopia.

Conflicts of Interest

The authors declare no conflict of interest.

Funding Declaration

The authors declare that no funds, grants, or other support was received during the preparation of this manuscript.

Consent to Publish Declaration

Informed consent was obtained from all individual participants included in the study.

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