Clinical and Epidemiologic Research

Time Outdoors and Myopia Progression Over 2 Years in Chinese Children: The Anyang Childhood Eye Study

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Purpose. To investigate whether time outdoors and a range of other activities are associated with change in spherical equivalent (SE) and axial length in Chinese children over a period of 2 years.

Methods. A total of 1997 children aged 12.7 ± 0.5 (10.9–15.6) years in the Anyang Childhood Eye Study (ACES) were examined annually (baseline and two follow-up visits). Myopia was defined as cycloplegic SE < -0.50 diopters (D). Questionnaires were administered to the students and parents at baseline to gauge time spent outdoors and on other tasks. We ran mixed linear models including age, sex, and years of follow-up.

Results. In the full cohort of children there was a suggestive association between time spent outdoors and change in axial length; however, the effect size was very small (high versus low tertile: −0.016 mm/y, $P = 0.053$). The association was observed in children not myopic at baseline (high versus low tertile, −0.036 mm/y; $P = 0.009$) but not in those already myopic at baseline (high versus low tertile: −0.005 mm/y; $P = 0.595$). Time outdoors and change in SE showed similar, but nonsignificant, relationships ($P > 0.05$), perhaps due to insufficient statistical power. The other activities examined and parental myopia were not associated with changes in SE and axial length ($P > 0.11$).

Conclusions. Within the normal range of variation encountered in these Chinese children, a wide range of activities were largely unrelated to myopia progression at this age. However, there was suggestive evidence that greater time outdoors was associated with slower axial elongation in nonmyopic teenagers, but not in existing myopes.

Keywords: myopia progression, children, axial elongation, time outdoors, near work

Myopia is one of the most prevalent ocular disorders among adults and children.[1] In adult white populations, myopia affects approximately 30% of the population,[2] and myopic retinopathy is already ranked the second to third cause of blindness in Caucasians.[3]

In mainland China,[4] Taiwan,[5] and Japan,[6] myopic retinopathy has been ranked the second cause of blindness among adults. In general, myopia has become an important cause of vision loss worldwide, and pathologic myopia affects up to 3% of the whole population in the world.[7]

Myopia prevalence in children was shown to vary significantly across different regions, ethnicities, and ages.[8–11] Myopia incidence and myopic shift in children also varied significantly. In Hong Kong, annual myopia incidence and myopic shift were 14% and –0.6 diopters (D) in children aged 5 to 16 years[12] and were 8% and –0.2 D in children aged 2 to 6 years.[13] In Singapore, these outcomes were 16% and –0.8 D in children aged 7 to 9 years.[14] To date, however, few studies have addressed the incidence and progression of myopia among children in mainland China.[15,16]

Most previous studies have reported that more time outdoors is associated with decreased myopia prevalence[17–21] and myopia incidence[22,23] in children, although two studies in children of Chinese ethnicity have failed to find such an association.[24,25] Progression of myopia has also been reported to be faster in winter than in summer,[26,27] indicative of a possible effect of time outdoors on slowing myopia progression. However, Jones-Jordan et al.[28] found no association between time outdoors and myopia progression in myopic children. An intervention trial also found a protective effect of outdoor activities in nonmyopic but not myopic subjects.[29] Therefore, it is still uncertain whether time outdoors inhibits myopia progression in children with existing myopia.[30] Changes in refractive error in school-age children are primarily dependent on axial elongation, which has not always been evaluated in previous studies.

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Here, we sought to evaluate whether time spent outdoors was predictive of future change in refractive error and axial length in a large sample of grade 7 Chinese children over a 2-year period of follow-up. Given that more than half of the children were already myopic at baseline, we also sought to provide a test of whether time outdoors was associated with slower myopia progression in existing myopes.

Materials and Methods

Study Population

The ACES was a school-based cohort study aiming to annually observe the prevalence, incidence, and progression of myopia among Chinese children in urban areas of Anyang, Henan Province, Central China. Details of the methodology have been previously reported.[11] The ACES was approved by the Ethics Committee of Beijing Tongren Hospital, Capital Medical University, and adhered to the tenets of the Declaration of Helsinki. Informed written consent was obtained from at least one parent of each child, as well as verbal assent from all children. During the period from October 2011 to December 2011, 2267 grade 7 students were examined, with a baseline response rate of 95.9%.[11] At the first and second follow-up, 93.5% and 83.3% of these students were reexamined, respectively.

Procedures

Cycloplegia was performed with one drop of topical anesthetic agent (Alcaine; Alcon, Fort Worth, TX, USA), followed by two drops of 1% cyclopentolate (Alcon) and one drop of tropicamide (Mydrin P; Santen, Osaka, Japan) at a 5-minute interval. Thirty minutes after the last drop, autorefraction was performed three times (HRK-7000A; Huvitz, Gunpo, Korea) and the average was used for analyses. The Lenstar LS900 (Haag-Streit, Koeniz, Switzerland) was used to measure axial length.

An interviewer-administered questionnaire was used for parents to identify the number of myopic parents.[31] Time outdoors and near work (h/d) were estimated by an interviewer-administered questionnaire from the students.[17,32] The time outdoors question included time engaged in the following outdoor activities: running; swimming; dancing; bicycle riding; playing football, table tennis, badminton, and basketball; exercise between classes; throwing sandbags; skipping rope; rubber band skipping; and kicking shuttlecocks. The near work question included time spent doing school homework, reading extracurricular books, handheld games, drawing, painting, writing, cooking, playing music, playing with pets, and playing chess and cards. The students were asked to identify whether the places for these activities were outdoor or indoor, and to fill out these activities separately for during the school year, the summer vacation, and the winter vacation. The average time performing the activity was calculated as time spent during school year $\times$ 9/12 + time spent in vacations $\times$ 3/12 according to the school term arrangement of Chinese children. Hours spent doing indoor and outdoor activities during the school day were assumed to be approximately constant for the whole cohort, and so were not individually calculated.

In the present study, the questionnaire on time outdoors had an overall intraclass correlation coefficient of 0.63 between two repeated surveys (with an interval of 3 weeks), a Cronbach's α coefficient for each item of 0.61, and load values of 12 items on common factors all greater than 0.4.[11] Time levels were divided into low, moderate, and high using population tertiles of the average daily hours spent in near work (0.29–2.50 h/d; 2.51–3.71 h/d; 3.72+ h/d) and outdoors (0–1.23 h/d; 1.24–2.27 h/d; 2.27+ h/d). To examine the association between environmental exposures and the development of myopia and high myopia, baseline measures for time outdoors and near work were used.[33]

Definitions

Refraction was calculated as the spherical equivalent (SE) averaged between the right and left eyes. We defined myopia as SE < -0.50 D. The number of myopic parents was determined from a questionnaire used in a previous study.[31] Myopia progression was considered to be any increase in the myopic SE in myopic children, while in the full cohort such a shift toward a more negative or less positive refractive error was termed a myopic shift. Change in axial length was calculated as the difference in axial length between sequential visits. Age from baseline was defined as the number of years from the first visit with values of 0 (i.e., baseline), 1, or 2.

Statistical Analysis

General statistical analysis was performed using SAS (v9.3; SAS Institute, Inc., Cary, NC, USA). Measures are presented as mean $\pm$ standard deviations (SD) for continuous variables and percentages for categorical variables. Association between exposure variables, changes in SE, and axial length during the follow-up period of 2 years were investigated using linear mixed models (*nlme* package for R, http://www.r-project.org/, in the public domain), in order to take account of the repeated measurements for individuals in the sample. A full description of this approach has been reported previously.[34] Briefly, individual-level random effects were used to explore how each child's change in SE and axial length differed based on time outdoors, near work, or number of myopic parents. Sex, age at baseline, and age from baseline (i.e., number of years from baseline) were included as fixed effects in each model. Exposure variables were coded as categorical variables (low, middle, and high tertiles). Each exposure variable was tested in a separate model to maximize statistical power. Because previous studies have reported an association between time outdoors and incident myopia but not between time outdoors and myopia progression, a model incorporating an interaction term between time outdoors and the presence/absence of myopia at baseline was also tested, that is, whether the effect of time outdoors differed depending on the child's myopia status at baseline. $P \leq 0.05$ was considered to be statistically significant. Similarly, we also ran a model that tested for an interaction between time spent outdoors (low, middle, or high tertile) and the number of myopic parents (0, 1, or 2).

Results

Of 2267 grade 7 students aged 10 to 15 years at baseline, 2140 (94.4%) were reexamined 1 year later, and 1890 (83.4%) were reexamined 2 years later. Mean age at baseline was 12.68 $\pm$ 0.48 years, and girls constituted 52.2% of the sample. There were no statistical differences in age, baseline refraction, number of myopic parents, or time spent outdoors, reading, doing homework, computer use, and video games between the 1890 participants who attended both follow-up assessments and the 377 who missed one or both follow-up visits. Among 1890 participants, 1724 had information available for at least one exposure variable.

Table 1 shows the baseline characteristics of the children. Boys spent significantly more time outdoors (2.35 vs. 1.82 h/d, $P < 0.01$) and on computer use (0.76 vs. 0.51 h/d, $P < 0.01$)

TABLE 1. Baseline Characteristics of the Study Cohort

	All	Girls	Boys	P
n	1890	987	903	
Age, y	12.68 ± 0.48	12.65 ± 0.48	12.70 ± 0.47	**0.02**
SE, D	−1.61 ± 2.06	−1.81 ± 2.09	−1.40 ± 1.99	**<0.01**
Axial length, mm	24.41 ± 1.13	24.18 ± 1.04	24.66 ± 1.17	**<0.01**
Parental myopia, n (%)				0.99
None	1111 (58.78)	599 (60.69)	512 (56.70)	
Either	401 (21.22)	217 (21.99)	184 (20.38)	
Both	109 (5.77)	59 (5.98)	50 (5.44)	
Reading, h/d	0.76 ± 0.70	0.74 ± 0.67	0.79 ± 0.73	0.20
Homework, h/d	1.71 ± 0.82	1.74 ± 0.82	1.67 ± 0.83	0.06
Computer use, h/d	0.64 ± 0.67	0.51 ± 0.52	0.76 ± 0.77	**<0.01**
Video games, h/d	0.42 ± 0.61	0.37 ± 0.60	0.47 ± 0.62	0.07
Time outdoors, h/d	2.07 ± 1.53	1.82 ± 1.31	2.35 ± 1.69	**<0.01**

Data are expressed as the mean ± SD; bold values indicate statistical significance ($P < 0.05$).

than girls yet reported a similar time performing reading (0.79 vs. 0.74 h/d, $P = 0.20$). Boys spent less time on homework (1.67 vs. 1.74 h/d, $P = 0.06$) and more time on video games (0.76 vs. 0.51 h/d, $P = 0.07$) with a borderline significance.

In the model that included the full cohort of participants, the mean change in SE per year in the sample was −0.48 (95% confidence interval [CI], −0.54 to −0.42) D, and the mean change in axial length per year was 0.24 (95% CI, 0.23–0.26) mm. Both age at baseline ($P < 0.01$) and age from baseline ($P < 0.01$) were positively associated with change in SE and negatively associated with change in axial length (Table 2), indicating that, on average, the older the child and the longer the period of follow-up, the slower the progression toward myopia (or the reduction in hyperopia) and the slower the rate of axial elongation. These age-related nonexposure variables were adjusted for in all subsequent the models, along with sex.

Although time outdoors was not associated with change in SE in the full cohort of children ($P > 0.19$; Table 3), or in those children who were or were not myopic at baseline ($P > 0.24$; Table 4; Fig. 1A), time outdoors had a borderline significant association with change in axial length in the full cohort of children (high versus low time outdoors tertile, $P = 0.054$; Table 3; Fig. 1B). This association was also observed in children who were not myopic at baseline (high versus middle tertile, $P = 0.024$; high versus low tertile, $P = 0.009$; Table 4) but not in children who were already myopic at baseline ($P = 0.996$ and $P = 0.595$, respectively; Table 4). Indeed, for the analysis of change in axial length there was a significant interaction between time outdoors and myopia status at baseline ($P = 0.015$ and $P = 0.010$, respectively; Table 5; Fig. 1B). There was no comparable interaction between time outdoors and number of myopic parents ($P > 0.26$; Table 5; Fig. 2B). Furthermore, no association with change in SE or with change in axial length was observed for any of the other exposure variables that were assessed.

Discussion

Our findings showed that in a school-based population of Chinese children aged 10 to 15 years in Central China, a wide range of indoor and outdoor activities showed little or no relationship with the changes in refractive error and axial length that occurred in the next 2 years. In fact, the only activity variable with evidence of an association with refractive error development was the time children spent outdoors, which had a borderline significant association with the rate of axial elongation over the 2-year follow-up period. Interestingly, the association with time outdoors appeared to be restricted to children who were not myopic at baseline (Table 4; Fig. 1B) and occurred in the direction that greater time outdoors was associated with a slower rate of axial elongation. Children already myopic at baseline showed a rate of axial elongation that did not vary significantly with the time they spent outdoors and that was faster than in those not myopic at baseline (Table 5; Fig. 1B). The relationship between time outdoors and change in SE showed the same trends as that between time outdoors and change in axial length (Table 4; Fig. 1A); however, there was no significant association between time outdoors and change in refractive error either in the full cohort (Table 3) or in children who were or were not myopic at baseline (Table 5). The most parsimonious explanation for the disparate results between the axial and refractive changes is that the models analyzing change in SE were less powerful than those for change in axial length—perhaps reflecting the greater accuracy and repeatability with which the latter can be measured[35]—and thus it seems likely that a lack of statistical power led to the results for change in SE failing to reach statistical significance. While the lack of consistency between

TABLE 2. Association Between Change in Spherical Equivalent (D/y) or Axial Length (mm/y) and Nonexposure Variables for the Model in the Full Cohort of Children

	Change in Spherical Equivalent			Change in Axial Length		
Variable	n	β, D/y (95% CI)	P	n	β, mm/y (95% CI)	P
Sex, referent = female	1646	−0.009 (−0.045 to 0.027)	0.61	1724	0.014 (0.001 to 0.027)	**0.04**
Age at baseline	1646	0.068 (0.030 to 0.105)	**<0.01**	1724	−0.021 (−0.035 to −0.007)	**<0.01**
Age from baseline	1646	0.055 (0.018 to 0.092)	**<0.01**	1724	−0.036 (−0.047 to −0.025)	**<0.01**

Bold values indicate statistical significance ($P < 0.05$).

TABLE 3. Association Between Change in Spherical Equivalent (D/y) or Change in Axial Length (mm/y) and Each Exposure Variable for the Full Cohort of Children

	Change in Spherical Equivalent			Change in Axial Length		
Exposure Variable, h/d	***n***	***β*, D/y (95% CI)**	***P***	***n***	***β*, mm/y (95% CI)**	***P***
Outdoor activity						
Middle tertile	1646	0.021 (−0.022 to 0.064)	0.337	1724	−0.011 (−0.027 to 0.005)	0.191
High tertile	1646	0.029 (−0.015 to 0.072)	0.196	1724	−0.016 (−0.032 to 0.000)	0.054
Indoor activity						
Middle tertile	1646	0.003 (−0.047 to 0.053)	0.897	1724	0.019 (−0.000 to 0.038)	0.052
High tertile	1646	0.016 (−0.024 to 0.056)	0.426	1724	−0.008 (−0.023 to 0.006)	0.257
Physical activity						
Middle tertile	1613	0.022 (−0.021 to 0.066)	0.314	1689	−0.005 (−0.021 to 0.011)	0.556
High tertile	1613	0.034 (−0.010 to 0.078)	0.132	1689	−0.016 (−0.032 to 0.001)	0.058
Reading						
Middle tertile	1522	0.024 (−0.021 to 0.069)	0.301	1596	−0.011 (−0.027 to 0.006)	0.209
High tertile	1522	0.016 (−0.028 to 0.060)	0.475	1596	−0.007 (−0.023 to 0.010)	0.426
Computer use						
Middle tertile	1300	0.001 (−0.047 to 0.050)	0.959	1355	−0.001 (−0.020 to 0.018)	0.927
High tertile	1300	−0.007 (−0.056 to 0.042)	0.779	1355	0.013 (−0.006 to 0.033)	0.176
Video games						
Middle tertile	449	0.011 (−0.071 to 0.093)	0.800	466	0.006 (−0.029 to 0.041)	0.745
High tertile	449	−0.008 (−0.094 to 0.079)	0.864	466	0.019 (−0.018 to 0.056)	0.316
Homework						
Middle tertile	1610	−0.006 (−0.050 to 0.038)	0.796	1687	0.001 (−0.016 to 0.017)	0.938
High tertile	1610	0.013 (−0.030 to 0.057)	0.547	1687	−0.007 (−0.023 to 0.010)	0.418

All exposure variables were divided into tertiles (referent = low); bold values indicate statistical significance ($P < 0.05$); all analyses were adjusted for sex, age at baseline, and age from baseline.

our axial and refractive findings do not allow us to draw definitive conclusions, they suggest that time spent outdoors is not predictive of myopia progression in existing myopes (unlike the reproducibly observed role of time outdoors in predicting incident myopia[22,23]).

In the present study, a range of near tasks—including reading, using a computer, playing video games, and doing homework—also were not associated with future changes in SE or axial length. Therefore, either these behaviors are not causally involved in the refractive shift toward myopia that occurred in the study cohort, on average, or the levels of variation in these behaviors within the study sample were too narrow for us to detect any associations; for example, potentially too few children spent a short enough time reading to reduce their incidence or progression of myopia relative to their peers. Recent work by Jones-Jordan et al.[36] demonstrated that child-specific environmental factors including near work and outdoor activity reduced the between-sibling correlation for refractive error by only 0.5%, suggesting that environmental factors such as outdoor activities have a limited impact on the degree of myopia, or that they have an impact only at specific time(s) during childhood that are not well captured by current measurement instruments. In a longitudinal study of 835 myopic children by the same research group,[28] there was no association between time outdoors and either myopia progression or axial elongation. Our findings were consistent with those of the latter study.[28] In contrast, Guo et al.[37] reported that axial elongation was significantly associated with less time spent outdoors ($P = 0.02$, standardized coefficient β –0.12) in 643 Beijing primary school children; however, there was no separate analysis in children who were or were not myopic at baseline.[37] The children in the study by Guo et al.[37] were

TABLE 4. Association of Time Outdoors With Change in Spherical Equivalent (D/y) or Change in Axial Elongation (mm/y) in Children Classified as Myopic and Nonmyopic at Baseline

	Change in Spherical Equivalent			Change in Axial Length		
Time Outdoors, h/d	***n***	***β*, D/y (95% CI)**	***P***	***n***	***β*, mm/y (95% CI)**	***P***
Myopic at baseline						
Middle tertile	1079	0.011 (−0.037 to 0.058)	0.659	1133	0.000 (−0.018 to 0.018)	0.996
High tertile	1079	−0.003 (−0.020 to 0.078)	0.242	1133	−0.005 (−0.024 to 0.014)	0.595
Nonmyopic at baseline						
Middle tertile	567	0.044 (−0.034 to 0.122)	0.270	591	−0.032 (−0.059 to −0.004)	**0.024**
High tertile	567	0.027 (−0.049 to 0.104)	0.487	591	−0.036 (−0.063 to −0.009)	**0.009**

Time outdoors was divided into tertiles (referent = low); bold values indicate statistical significance ($P < 0.05$); all analyses were adjusted for sex, age at baseline, and age from baseline.

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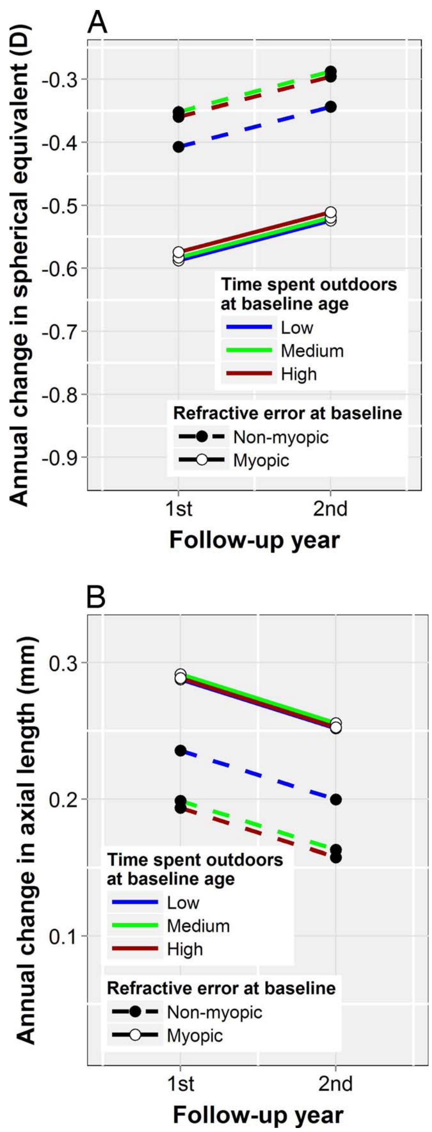

FIGURE 1. Association between time outdoors and annual change in spherical equivalent (**A**) and between time outdoors and annual change in axial length (**B**) among myopic and nonmyopic children, respectively. The *points* and *lines* show predictions from the best-fit linear mixed model that included sex, age at baseline, and age from baseline.

mostly younger (range, 5–13, mean, 7.7 years) than those studied here, which may account for the difference in results.

French et al.[30] have argued that the failure of the time outdoors to show an association with myopia progression, as opposed to myopia incidence, is likely to be a statistical problem, given that myopic children tend to be derived from a segment of the population who tend to do more near work and spend less time outdoors. This would limit the amount of variation within the population of those with existing myopia, making statistical significance more difficult to achieve. In our study cohort, myopic and nonmyopic children spent similar amounts of time outdoors (2.04 vs. 2.17 h/d, $P = 0.08$), and the variance in time outdoors was also similar in myopes and nonmyopes (Table 1). This makes it unlikely that differences in time spent outdoors—at least at the age at which the information was collected here—could explain the faster myopic shift we observed in myopic versus nonmyopic children. A threshold effect of time outdoors on myopia progression has also been suggested to explain the difference in effect observed previously between myopic and nonmyopic children.[30]

Consistent with some previous studies,[23,38] we found a weak positive correlation between near tasks and outdoor activities. Such results support the idea[18] that any protective effect of time outdoors against myopia is not simply due to a reduction in near work. Seasonal differences in progression rates[26,27] and the small number of intervention trials published to date[29,39] (Morgan IG, et al. *IOVS* 2012;53:E-Abstract 2753) support the theory that spending more time outdoors can slow the incidence—and possibly the progression—of myopia in children. Future research in this area will be important in providing an evidence base for the use of increased time outdoors, or increased exposure to bright lighting, as a potential therapy.

Strengths of our study were that it included a large number of children in a setting in which a high proportion typically develop myopia; it had a high response to follow-up; and it included data on both cycloplegic autorefraction and axial length. Although ACES is a school-based, not a population-based cohort study, the attendance of students in Anyang was greater than 99% due to the compulsory education system. However, a potential limitation should be mentioned: Time spent outdoors and time performing near tasks were self-reported. This could have been a source of recall bias, although this type of questionnaire-based assessment has been adopted widely, including in studies that found strong associations between time outdoors and myopia.[17,30,32]

TABLE 5. Tests for Interaction Between Time Outdoors, and Either the Presence/Absence of Myopia at Baseline or the Number of Myopic Parents

	Change in Spherical Equivalent			Change in Axial Length		
	n	***β*, D/y (95% CI)**	***P***	***n***	***β*, mm/y (95% CI)**	***P***
Myopic at baseline × time outdoors, middle vs. low	1646	−0.051 (−0.140 to 0.038)	0.262	1724	0.041 (0.008 to 0.073)	**0.015**
Myopic at baseline × time outdoors, high vs. low	1646	−0.034 (−0.122 to 0.054)	0.449	1724	0.043 (0.010 to 0.076)	**0.010**
Number of myopic parents, 1 vs. 0 × time outdoors, middle vs. low	1426	0.061 (−0.047 to 0.170)	0.268	1487	−0.015 (−0.055 to 0.026)	0.481
Number of myopic parents, 2 vs. 0 × time outdoors, middle vs. low	1426	0.055 (−0.139 to 0.248)	0.580	1487	−0.033 (−0.106 to 0.040)	0.380
Number of myopic parents, 1 vs. 0, × time outdoors, high vs. low	1426	−0.020 (−0.129 to 0.089)	0.720	1487	0.011 (−0.030 to 0.052)	0.592
Number of myopic parents, 2 vs. 0 × time outdoors, high vs. low	1426	0.058 (−0.128 to 0.244)	0.541	1487	−0.038 (−0.111 to 0.035)	0.303

Time outdoors (referent = low); myopic at baseline (referent = not myopic); number of myopic parents (referent = 0); bold values indicate statistical significance ($P < 0.05$); all analyses were adjusted for sex, age at baseline, and age from baseline.

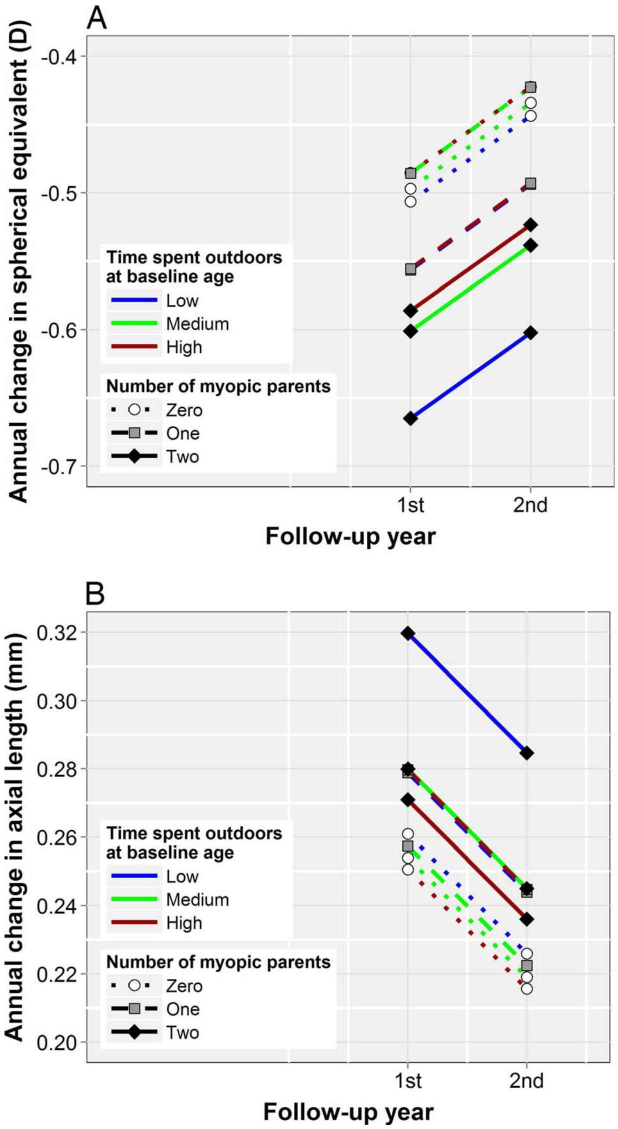

FIGURE 2. The interaction between time outdoors and number of myopic parents for association with annual change in spherical equivalent (**A**) and annual change in axial length (**B**). The *points* and *lines* show predictions from the best-fit linear mixed model that included sex, age at baseline, age from baseline, and myopia status at baseline.

In summary, this prospective cohort study revealed that time outdoors was not significantly associated with change in refractive error or change in axial length over a 2-year period in a population of Chinese children aged 10 to 15 years. In children who were not myopic at baseline, the rate of axial elongation was lower (by ~0.03 D/y; $P < 0.05$) in children who spent more time outdoors, yet this was not matched by a slower shift toward a more myopic refractive error—possibly due to insufficient statistical power to detect such a small effect. The rate of axial elongation was not associated with time spent outdoors in the children who were already myopic at baseline.

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Appendix

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