Outdoor Jogging and Myopia Progression in School Children From Rural Beijing: The Beijing Children Eye Study

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Purpose: To assess the influence of an outdoor program on myopia progression in school children.

Methods: The prospective interventional school-based study included 373 students aged 6 to 7 years (grade 1 or 2) who were examined annually between 2012 and 2016. Between 2012 and 2013, the children in the study group (n = 157) performed a 30-minute jogging exercise every school day, while the children in the control school (n = 216) did not. All children underwent a comprehensive ocular examination, including biometry.

Results: At 1 year after baseline, axial elongation and progression of myopic refractive error were significantly lower in the study group than in the control group. Study group and control group differed in axial elongation only in the subgroup of children nonmyopic at baseline, while axial elongation in the children myopic at baseline did not differ between both groups. At 1 and 2 years after the outdoor program stopped, increase in axial length was significantly larger in the study group. At 4 years after baseline, study group and control group did not differ significantly in total axial elongation and total change in refractive error.

Conclusions: An outdoor program of 30 minutes performed every school day for 1 year temporarily reduced myopia progression in schoolchildren nonmyopic at baseline, with a complete rebound effect after the program ended within the 3 following years.

Translational Relevance: An outdoor program of 30 minutes performed every school day for 1 year temporarily reduced the progression of myopia in schoolchildren nonmyopic at baseline for the period when the program was carried out.

Introduction

The marked increase in the prevalence of myopia has become a major public health issue in East Asia, in particular in China.¹⁻¹¹ In a recent survey, the prevalence of myopia defined as a myopic refractive error of −0.50 diopters or greater increased from 1.7% (95% confidence interval [CI]: 0.0, 4.0) in children with an age of 4 years to 84.6% (95% CI: 78.0, 91.0) in children aged 17 years.⁷ The prevalence of high myopia (defined as a myopic refractive error of −6.0 diopters or greater) increased from 0.7% (95% CI: 0.1, 1.3) in children with an age of 10 years to 13.9% (95% CI: 7.8, 19.9) in children aged 17 years.⁷ The early onset of myopia was associated with a faster and longer duration of myopia progression and, consequently, with a higher risk of developing high myopia later in life.¹² Since high myopia can lead myopic maculopathy and myopia-associated glaucomatous optic neuropathy, myopia may become one of the main reasons for irreversible blindness.³,¹³,¹⁴

An association between an higher amount of outdoor activities and a lower prevalence and incidence of myopia has been shown by numerous
Two elementary schools in a rural region area of Greater Beijing were included in this study. At baseline of the prospective interventional study in the year 2012, students of grade 1 (age: 6 years) and grade 2 (age: 7 years) were ophthalmologically examined. Informed written consent was obtained from at least one parent per child. The Human Research Ethics Committee of the TongRen Hospital at Capital Medical University Beijing approved the study design. One school was located in the rural Beijing Fang Shan district, an area with an average annual income of 10,777 Yuan (US $1592) in 2010 (average income across all Beijing: 19,640 Yuan, or US $2901), at a distance of 58 km from the city center. The other school was located in the rural Beijing Huai Rou district, with an average income of 11,012 Yuan (US $1627), located in the southeast of Beijing at a distance of 60 km from the city center. The schools were selected based on their similarity in the socioeconomic status of the local districts. The school in the Fang Shan district served as the study school, whereas the school in the Beijing Huai Rou district served as the control school. In the period from 2012 to 2013, the children in the study school had to spend their free time during the school breaks outside the classrooms. Under the guidance and surveillance of teachers, the students were organized to jog in the school yard during the break time. Talking was not allowed during this activity. The total time spent daily outdoors for this special program was 30 minutes. The program was conducted every weekday unless bad weather did not allow staying outdoors for long. The exercise was organized by one teacher and one monitor of each class, and it was supervised by the director of the school during the school breaks. In the control school, the school children continued their normal lifestyle without any intervention. The baseline examination of the study was conducted in 2012, and the examinations were repeated yearly until 2016.

The eye examination carried out for all study participants consisted of refractometry and measurement of visual acuity, an evaluation of ocular motility, slit-lamp–assisted biomicroscopy of the anterior and posterior segments of the eye, and nonmydriatic digital fundus photography (45°, CR-DGI camera; Canon Inc., Tokyo, Japan). Applying optical low-coherence reflectometry (Lenstar 900 Optical Biometer; Haag-Streit, Koeniz, Switzerland), the ocular biometric parameters of central corneal thickness, corneal curvature radius, anterior chamber depth, lens thickness, and axial length were measured in the right eyes of all children. The axial length/corneal curvature radius (ALCC) ratio was calculated. The refractive error was measured in a non-cycloplegic state, first automatically (auto-refractor KR-8900; Topcon Corp., Tokyo, Japan) and then subjectively. In an attempt to prevent accommodation by the young study participants under the non-cycloplegic conditions, the assessment of refractive error routinely started using correcting lenses of about +6 diopters, followed by slowly decreasing the refractive power of the correcting lens until the children achieved best-corrected visual acuity. The interview of the parents consisted of a questionnaire with questions about the children’s family history,
time spent outdoors, activities performed outdoors, time spent indoors, and activities carried out indoors. The time per day spent outdoors, except for the school time, was assessed in the interview about the children’s daily activities. The questionnaire included questions how long the children took to get to school and to return home, what kind of transportation (walking, bicycle, private car, public transport) was taken, how long the children spent outdoors during school breaks, and what kind of sport they played and how long they performed the sport during the week and during the weekends. The interview additionally included questions about the time used to study indoors. The average time spent daily on these activities was calculated. The assessment of the time spent outdoors was based on questions about playing outdoors, having picnics, walking, and outdoor sport. The average number of daily outdoor activity hours was calculated using the formula: \( \frac{(\text{hours spent on a weekday}) 	imes 5 + (\text{hours spent on a weekend day}) 	imes 2}{7} \). Myopia was defined as a spherical equivalent refractive error (sphere + 1/2 cylinder) of at least −0.50 diopters.

The main outcome parameter was the progression toward myopia and the progression of myopia, measured by the axial elongation of the eye and the change in the ALCC ratio and refractive error during the study period.

Statistical analysis was performed using a statistical software package (SPSS for Windows, version 25.0; SPSS, Chicago, IL). Data from the right eyes were analyzed. The parameters were presented as the mean ± standard deviation. In a first step, we assessed differences between the study and the control group in baseline parameters and in the change in the ocular measurements between the baseline examination and the follow-up examinations. We applied the \( t \)-test for independent samples and the \( \chi^2 \) test. In a second step, we examined parameters that were associated with the progression of myopia and axial elongation in a univariate analysis and finally in a multivariable analysis. The latter included all those parameters as independent variables that were significantly correlated with myopia progression in the univariate analysis. We then dropped step-by-step those parameters that were no longer significantly associated myopia progression. We calculated the standardized regression coefficient \( \beta \), the nonstandardized regression coefficient \( B \), odds ratios (ORs), and the 95% CIs. All \( P \) values were two-sided and were considered statistically significant when the values were less than 0.05.

### Results

A total of 373 children were enrolled in this study, with 157 children in the study group and 216 pupils in the control group. At baseline of the study, the study group and the control group did not differ significantly in age (\( P = 0.69 \)), gender (\( P = 0.83 \)), axial length (\( P = 0.24 \)), refractive error (\( P = 0.08 \)), time spent with indoor activities (\( P = 0.88 \)), and time spent with outdoor activities (\( P = 0.89 \)) (Table 1). The ALCC ratio was significantly higher (\( P = 0.008 \)) in the study group than in the control group (Table 1). The proportion of children myopic at baseline and the proportion of children nonmyopic at baseline did not differ significantly between the study group (myopic: \( n = 62 \), nonmyopic: \( n = 95 \)) and the control group (myopic: \( n = 74 \); nonmyopic: \( n = 142 \); \( P = 0.33 \)) (Table 2).

After 1 year of follow-up, axial elongation (0.25 ±
### Table 2. Characteristics (Mean ± Standard Deviation) of the Study Group and Control Group at 1 Year Follow-Up

| Parameters                                                                 | Intervention Group ($n = 157$) | Control Group ($n = 216$) |
|---------------------------------------------------------------------------|-------------------------------|---------------------------|
| **Total**                                                                 |                               |                           |
| Refractive error, diopters                                               | $-0.13 ± 0.85$               | $-0.23 ± 0.86$            |
| $n$ (becoming myopic during study period of 1 year)                       | 33 (21.0%; 95% CI: 14.6, 27.5) | 74 (34.3%; 95% CI: 27.9, 40.6) |
| Change in refractive error, diopters                                      | $-0.05 ± 0.97$               | $-0.33 ± 0.70$            |
| Progression of refractive error by greater than $-0.00$ diopters          | 49.0% (95% CI: 41.1, 57.0)    | 69.4% (95% CI: 63.3, 75.6) |
| Progression of a refractive error by greater than $-0.50$ diopters        | 22.9% (95% CI: 16.3, 29.6)    | 32.9% (95% CI: 26.6, 39.2) |
| Progression of refractive error by greater than $-1.00$ diopters          | 8.3% (95% CI: 3.9, 12.6)      | 13.4% (95% CI: 8.8, 18.0)  |
| Axial length, mm                                                          | 22.87 ± 0.76                  | 22.83 ± 0.83              |
| Increase in axial length, mm                                              | 0.25 ± 0.20                   | 0.30 ± 0.17               |
| ALCC radius ratio                                                         | 2.943 ± 0.094                 | 2.929 ± 0.073             |
| Increase in ALCC radius ratio                                             | 0.026 ± 0.043                 | 0.033 ± 0.031             |
| **Nonmyopic Children at Baseline**                                        |                               |                           |
| $n$ nonmyopic children at baseline                                        | 95                            | 142                       |
| Refractive error, diopters                                               | $0.13 ± 0.72$                 | $0.01 ± 0.81$             |
| $n$ (becoming myopic during study period of 1 year)                       | 33 (34.7%; 95% CI: 25.0, 44.5) | 74 (52.1%; 95% CI: 43.8, 60.4) |
| Change in refractive error, diopters                                      | $-0.34 ± 0.60$               | $-0.47 ± 0.56$            |
| Progression of refractive error by greater than $-0.00$ diopters          | 59.0% (95% CI: 48.9, 69.0)    | 76.1% (95% CI: 69.0, 83.2) |
| Progression of a refractive error by greater than $-0.50$ diopters        | 30.5% (95% CI: 21.1, 40.0)    | 40.1% (95% CI: 32.0, 48.3) |
| Progression of refractive error by greater than $-1.00$ diopters          | 11.6% (95% CI: 5.0, 18.1)     | 16.2% (95% CI: 10.1, 22.3) |
| Axial length, mm                                                          | 22.76 ± 0.73                  | 22.77 ± 0.81              |
| Change in axial length, mm                                                | 0.23 ± 0.22                   | 0.31 ± 0.16               |
| ALCC ratio                                                                | 2.919 ± 0.097                 | 2.921 ± 0.067             |
| Change in ALCC ratio                                                      | 0.023 ± 0.052                 | 0.032 ± 0.030             |
| **Myopic Children at Baseline**                                           |                               |                           |
| $n$                                                                       | 62                            | 74                        |
| Refractive error, diopters                                               | $-0.52 ± 0.89$               | $-0.69 ± 0.74$            |
| Change in refractive error, diopters                                      | $0.28 ± 0.83$                 | $-0.06 ± 0.86$            |
| Progression of refractive error by greater than $-0.00$ diopters          | 33.9% (95% CI: 21.8, 46.0)    | 56.8% (95% CI: 45.2, 68.3) |
| Progression of a refractive error by greater than $-0.50$ diopters        | 11.3% (95% CI: 3.2, 19.4)     | 18.9% (95% CI: 9.8, 28.1)  |
| Progression of refractive error by greater than $-1.00$ diopters          | 3.2% (95% CI: −1.3, 7.8)      | 8.1% (95% CI: 1.7, 14.5)  |
| Axial length, mm                                                          | 23.06 ± 0.79                  | 22.94 ± 0.85              |
| Change in axial length, mm                                                | 0.29 ± 0.13                   | 0.30 ± 0.18               |
| ALCC ratio                                                                | 2.979 ± 0.075                 | 2.946 ± 0.081             |
| Change in ALCC ratio                                                      | 0.031 ± 0.024                 | 0.034 ± 0.035             |
| Parameters                                                                 | Estimated Difference or OR | 95% CI          | P Value |
|---------------------------------------------------------------------------|-----------------------------|-----------------|---------|
| **Total**                                                                 |                             |                 |         |
| Refractive error, diopters                                               | −0.10                       | −0.28, 0.07     | 0.26    |
| n (becoming myopic during study period of 1 year)                        | 0.51                        | 0.32, 0.82      | 0.005   |
| Change in refractive error, diopters                                      | −0.28                       | −0.46, −0.10    | 0.002   |
| Progression of refractive error by greater than −0.00 diopters           | 20.4                        | 10.4, 30.4      | <0.001  |
| Progression of a refractive error by greater than −0.50 diopters         | 9.9                         | 0.8, 19.1       | 0.03    |
| Progression of refractive error by greater than −1.00 diopters           | 5.1                         | −1.2, 11.4      | 0.11    |
| Axial length, mm                                                          | −0.04                       | −0.21, 0.12     | 0.60    |
| Increase in axial length, mm                                              | 0.05                        | 0.01, 0.09      | 0.008   |
| ALCC ratio                                                                | −0.014                      | −0.032, −0.004  | 0.13    |
| Increase in ALCC radius ratio                                             | 0.004                       | −0.001, 0.015   | 0.08    |
| **Nonmyopic Children at Baseline**                                        |                             |                 |         |
| n nonmyopic children at baseline                                          |                             |                 |         |
| Refractive error, diopters                                               | −0.12                       | −0.32, 0.08     | 0.25    |
| n (becoming myopic during study period of 1 year)                        | 0.49                        | 0.29, 0.84      | 0.01    |
| Change in refractive error, diopters                                      | −0.13                       | −0.28, −0.02    | 0.09    |
| Progression of refractive error by greater than −0.00 diopters           | 0.45                        | 0.26, 0.79      | 0.006   |
| Progression of a refractive error by greater than −0.50 diopters         | 0.66                        | 0.38, 1.14      | 0.17    |
| Progression of refractive error by greater than −1.00 diopters           | 0.68                        | 0.31, 1.47      | 0.35    |
| Axial length, mm                                                          | 0.01                        | −0.19, 0.22     | 0.89    |
| Change in axial length, mm                                                | 0.08                        | 0.02, 0.12      | 0.003   |
| ALCC ratio                                                                | 0.001                       | −0.22, 0.025    | 0.90    |
| Change in ALCC ratio                                                      | 0.010                       | −0.001, 0.020   | 0.07    |
| **Myopic Children at Baseline**                                           |                             |                 |         |
| n                                                                        |                             |                 |         |
| Refractive error, diopters                                               | −0.17                       | −0.45, 0.11     | 0.24    |
| Change in refractive error, diopters                                      | −0.34                       | −0.63, −0.05    | 0.02    |
| Progression of refractive error by greater than −0.00 diopters           | 0.39                        | 0.19, 0.79      | 0.01    |
| Progression of a refractive error by greater than −0.50 diopters         | 0.55                        | 0.21, 1.45      | 0.24    |
| Progression of refractive error by greater than −1.00 diopters           | 0.38                        | 0.07, 1.94      | 0.29    |
| Axial length, mm                                                          | −0.12                       | −0.40, 0.17     | 0.42    |
| Change in axial length, mm                                                | 0.01                        | −0.04, 0.07     | 0.61    |
| ALCC ratio                                                                | −0.033                      | −0.060, −0.006  | 0.016   |
| Change in ALCC ratio                                                      | 0.003                       | −0.001, 0.013   | 0.58    |
0.20 vs. 0.30 ± 0.17 mm; $P = 0.008$) and progression in myopic refractive error ($-0.05 ± 0.97$ vs. $-0.33 ± 0.70$ diopters; $P = 0.002$) were significantly lower in the study group than in the control group (Table 2) (Figs. 1–4). Any myopic progression of refractive error and progression of refractive error by more than $-0.50$ diopters into the direction of myopia was significantly ($P < 0.001; P = 0.03$, respectively) less frequent in the study group than in the control group (Table 2). The incidence of myopia was significantly higher in the control group than in the study group for the children who were not myopic at baseline (52.1% [95% CI: 43.8, 60.4] vs. 34.7% [95% CI: 25.0, 44.5]; OR: 0.49 [95% CI: 0.29, 0.84]; $P = 0.01$). As a corollary, the incidence of myopia combined with the frequency of the event of myopia progression was significantly higher in the control group than in the study group for the total study population (34.3% [95% CI: 27.9, 40.6] vs. 21.0% [95% CI: 14.6, 27.5]; OR: 0.51 [95% CI: 0.32, 0.82]; $P = 0.005$) (Table 2). In multivariable regression, longer axial elongation was associated with the control group versus study group ($P = 0.005; \beta: 0.15; \beta: 0.05; 95\% \text{ CI}: 0.02, 0.09$) after adjusting for female sex ($P = 0.03; \beta: 0.13; \beta: 0.05$;
significantly (the study, the amount of axial elongation did not differ 0.08 mm and 0.13 diopters. Since the differences between both groups were only difference in axial elongation, was relatively small being statistically significant in the case of the clinical significance of these differences, despite ending the outdoors program; 0.27
length in the period from 2013 to 2014 (first year after ending the outdoor program, the increase in axial length in the period from 2014 to 2015 (in the second year after ending the outdoor program) was again significantly larger (0.29 ± 0.23 vs. 0.20 ± 0.26 mm; P = 0.002) in the study group than in the control group, while the difference in the progression in myopic refractive error (−0.30 ± 0.81 vs. −0.17 ± 0.74 diopters; P = 0.13) was not statistically significant (Figs. 1, 2).

At the end of the study, after 4 years of follow-up, the increase in axial length in the period from 2015 to 2016 (in the third year after ending the outdoor program) was again significantly larger (0.29 ± 0.23 vs. 0.20 ± 0.26 mm; P = 0.51) and the progression in myopic refractive error (−0.27 ± 0.71 vs. −0.23 ± 0.68 diopters; P = 0.56) did not differ significantly between the study group and the control group (Figs. 1, 2). During the total follow-up period, the study group and control group did not differ significantly in the change in refractive error (P = 0.28); in the frequency of a change in refractive error by more than 0 diopters (P = 0.10), by more than −0.50 diopters (P = 0.44), and by more than −1.0 diopters (P = 0.40); in axial elongation (P = 0.16); and in change in the ALCC ratio (P = 0.23) (Table 4). As a corollary, the incidence of myopia did not vary significantly between the study group and the control group for the total study population (P = 0.64) or for the group of children being nonmyopic at baseline of the study (P = 1.00) (Table 3).

After 3 years of follow-up and at 2 years after ending the outdoor program, the increase in axial length in the period from 2014 to 2015 (in the second year after ending the outdoor program) was again significantly larger (0.29 ± 0.13 vs. 0.23 ± 0.22 mm; P = 0.14) and within the control group (0.30 ± 0.18 vs. 0.31 ± 0.16 mm; P = 0.13) did not differ significantly. In a similar manner, the increase in myopic refractive error between the group myopic at baseline and the group nonmyopic at baseline within the study group (−0.39 ± 0.72 vs. −0.28 ± 0.62 diopters; P = 0.35) and within the control group (−0.09 ± 0.71 vs. −0.04 ± 0.63 diopters; P = 0.62) did not differ significantly. As a corollary, the incidence of myopia did not vary significantly between the study group and the control group for the total study population (P = 0.64) or for the group of children being nonmyopic at baseline of the study (P = 1.00) (Table 3).

95% CI: 0.01, 0.09) and longer axial length at baseline (P = 0.01; β: 0.15; B: 0.04; 95% CI: 0.01, 0.06).

In the children who were not myopic at baseline, the amount of axial elongation was statistically significantly (0.23 ± 0.22 vs. 0.31 ± 0.16 mm; P = 0.003) smaller in the study group than in the control group, while the difference in the change in myopic refractive error (−0.34 ± 0.60 vs. −0.47 ± 0.56 diopters; P = 0.09) and the change in the ALCC ratio (P = 0.07) did not reach the level of statistical significance (Table 2). The clinical significance of these differences, despite being statistically significant in the case of the difference in axial elongation, was relatively small since the differences between both groups were only 0.08 mm and 0.13 diopters.

In the children who were myopic at baseline of the study, the amount of axial elongation did not differ significantly (P = 0.62) between the study group and the control group (0.29 ± 0.13 vs. 0.30 ± 0.18 mm).

After 2 years of follow-up and at 1 year after ending the outdoor program, the increase in axial length in the period from 2013 to 2014 (first year after ending the outdoors program; 0.27 ± 0.20 vs. 0.20 ± 0.15 mm; P = 0.001) and progression in myopic refractive error (−0.32 ± 0.66 vs. −0.06 ± 0.66 diopters; P < 0.001) were significantly larger in the study group than in the control group (Table 3; Figs. 1, 2). The increase in axial length in the period from 2013 to 2014 between the group myopic at baseline and the group nonmyopic at baseline within the study group (0.29 ± 0.13 vs. 0.23 ± 0.22 mm; P = 0.14) and within the control group (0.30 ± 0.18 vs. 0.31 ± 0.16 mm; P = 0.13) did not differ significantly. In a similar manner, the increase in myopic refractive error between the group myopic at baseline and the group nonmyopic at baseline within the study group (−0.39 ± 0.72 vs. −0.28 ± 0.62 diopters; P = 0.35) and within the control group (−0.09 ± 0.71 vs. −0.04 ± 0.63 diopters; P = 0.62) did not differ significantly. As a corollary, the incidence of myopia did not vary significantly between the study group and the control group for the total study population (P = 0.64) or for the group of children being nonmyopic at baseline of the study (P = 1.00) (Table 3).
**Table 3.** Characteristics (Mean ± Standard Deviation) of the Study Group and Control Group After 2 Years of Follow-Up and at 1 Year After Ending the Outdoors Program

| Parameters | Intervention Group | Control Group |
|------------|--------------------|---------------|
|            | *(n = 157)*        | *(n = 216)*   |
| **Total**  |                    |               |
| Refractive error, diopters | -0.41 ± 1.00 | -0.28 ± 1.04 |
| n (becoming myopic during study period of 2 years) | 41 (26.1%; 95% CI: 19.2, 33.1) | 62 (28.7%; 95% CI: 22.6, 34.8) |
| Change in refractive error, diopters | -0.32 ± 0.66 | -0.06 ± 0.66 |
| Progression of refractive error by greater than -0.00 diopters | 64.6% (95% CI: 56.7, 72.5) | 63.3% (95% CI: 56.8, 69.9) |
| Progression of a refractive error by greater than -0.50 diopters | 39.6% (95% CI: 31.5, 47.7) | 37.6% (95% CI: 31.0, 44.2) |
| Progression of refractive error by greater than -1.00 diopters | 18.8% (95% CI: 12.3, 25.2) | 17.6% (95% CI: 12.4, 22.8) |
| Axial length, mm | 23.14 ± 0.77 | 23.02 ± 0.87 |
| Increase in axial length, mm | 0.27 ± 0.20 | 0.20 ± 0.15 |
| ALCC radius ratio | 2.981 ± 0.085 | 2.959 ± 0.082 |
| Increase in ALCC radius ratio | 0.041 ± 0.044 | 0.030 ± 0.024 |
| **Nonmyopic Children at Baseline** |                    |               |
| n, nonmyopic children at baseline | 95               | 142           |
| Change in refractive error, diopters | -0.12 ± 0.75 | -0.01 ± 0.93 |
| n (becoming myopic during study period of 2 years) | 41 (43.2%; 95% CI: 33.0, 53.3) | 62 (43.7%; 95% CI: 35.4, 51.9) |
| Change in refractive error, diopters | -0.28 ± 0.62 | -0.04 ± 0.63 |
| Progression of refractive error by greater than -0.00 diopters | 75.6% (95% CI: 66.3, 84.9) | 73.2% (95% CI: 65.7, 80.7) |
| Progression of a refractive error by greater than -0.50 diopters | 45.3% (95% CI: 34.6, 56.1) | 40.6% (95% CI: 32.2, 48.9) |
| Progression of refractive error by greater than -1.00 diopters | 19.8% (95% CI: 11.1, 28.4) | 15.9% (95% CI: 9.8, 22.1) |
| Axial length, mm | 23.01 ± 0.73 | 22.96 ± 0.85 |
| Change in axial length, mm | 0.25 ± 0.22 | 0.19 ± 0.14 |
| ALCC radius ratio | 2.958 ± 0.079 | 2.950 ± 0.075 |
| Change in ALCC radius ratio | 0.039 ± 0.052 | 0.029 ± 0.023 |
| **Myopic Children at Baseline** |                    |               |
| n | 62 | 74 |
| Refractive error (diopters) | -0.85 ± 1.16 | -0.79 ± 1.06 |
| Change in refractive error, diopters | -0.39 ± 0.72 | -0.09 ± 0.71 |
| Progression of refractive error by greater than -0.00 diopters | 48.3% (95% CI: 35.0, 61.5) | 44.4% (95% CI: 32.7, 56.2) |
| Progression of a refractive error by greater than -0.50 diopters | 31.0% (95% CI: 18.8, 43.3) | 31.9% (95% CI: 20.9, 43.0) |
| Progression of refractive error by greater than -1.00 diopters | 17.2% (95% CI: 7.2, 27.3) | 20.8% (95% CI: 11.1, 30.4) |
| Axial length, mm | 23.33 ± 0.80 | 23.14 ± 0.91 |
| Change in axial length, mm | 0.29 ± 0.17 | 0.22 ± 0.16 |
| Axial ALCC radius ratio | 3.016 ± 0.083 | 2.978 ± 0.093 |
| Change in ALCC radius ratio | 0.043 ± 0.027 | 0.032 ± 0.027 |
### Table 3. Extended

| Parameters | Estimated Difference | 95% CI      | P Value |
|------------|----------------------|-------------|---------|
| **Total**  |                      |             |         |
| Refractive error, diopters | 0.14 | -0.08, 0.35 | 0.21 |
| Change in refractive error, diopters | 0.26 | 0.12, 0.40 | <0.001 |
| Progression of refractive error by greater than −0.00 diopters | 1.06 | 0.68, 1.64 | 0.82 |
| Progression of a refractive error by greater than −0.50 diopters | 1.09 | 0.70, 1.68 | 0.74 |
| Progression of refractive error by greater than −1.00 diopters | 1.08 | 0.62, 1.87 | 0.78 |
| Axial length, mm | 0.26 | 0.12, 0.40 | <0.001 |
| Increase in axial length, mm | -0.07 | -0.10, -0.03 | 0.001 |
| ALCC radius ratio | -0.021 | -0.039, -0.004 | 0.02 |
| Increase in ALCC radius ratio | -0.011 | -0.019, -0.003 | 0.008 |
| **Nonmyopic Children at Baseline** | | | |
| Refractive error, diopters | 0.11 | -0.11, 0.34 | 0.36 |
| Change in refractive error, diopters | 0.24 | 0.06, 0.41 | 0.007 |
| Progression of refractive error by greater than −0.00 diopters | 1.13 | 0.61, 2.11 | 0.76 |
| Progression of a refractive error by greater than −0.50 diopters | 1.22 | 0.71, 2.09 | 0.49 |
| Progression of refractive error by greater than −1.00 diopters | 1.30 | 0.65, 2.62 | 0.47 |
| Axial length, mm | -0.05 | -0.27, 0.15 | 0.59 |
| Change in axial length, mm | -0.06 | -0.11, -0.01 | 0.02 |
| ALCC radius ratio | -0.008 | -0.27, 0.012 | 0.43 |
| Change in ALCC radius ratio | -0.010 | -0.021, 0.002 | 0.10 |
| **Myopic Children at Baseline** | | | |
| Refractive error (diopters) | 0.06 | -0.33, 0.46 | 0.74 |
| Change in refractive error, diopters | 0.29 | 0.04, 0.54 | 0.02 |
| Progression of refractive error by greater than −0.00 diopters | 1.17 | 0.58, 2.34 | 0.73 |
| Progression of a refractive error by greater than −0.50 diopters | 0.96 | 0.46, 2.02 | 1.00 |
| Progression of refractive error by greater than −1.00 diopters | 0.79 | 0.33, 1.92 | 0.66 |
| Axial length, mm | -0.19 | -0.48, 0.11 | 0.21 |
| Change in axial length, mm | -0.07 | -0.13, -0.02 | 0.01 |
| Axial ALCC radius ratio | -0.038 | -0.068, -0.008 | 0.014 |
| Change in ALCC radius ratio | -0.012 | -0.021, -0.002 | 0.01 |
Table 4. Comparing Primary End Points (Mean ± Standard Deviation) Between the Study Group and Control Group at 4 Years After Baseline

| Parameters | Intervention Group (n = 157) | Control Group (n = 216) |
|------------|-----------------------------|------------------------|
| **Total**  |                             |                        |
| Refractive error in 2016, diopters | -1.02 ± 1.61          | -0.69 ± 1.44          |
| n (becoming myopic during study period of 4 years) | 50 (31.9%; 95% CI: 24.5, 39.2) | 79 (36.6%; 95% CI: 30.1, 43.1) |
| Change in refractive error, diopters | -0.95 ± 1.50          | -0.79 ± 1.25          |
| Progression of refractive error by greater than −0.00 diopters | 77.1% (95% CI: 70.4, 83.7) | 69.4% (95% CI: 63.3, 75.6) |
| Progression of refractive error by greater than −0.50 diopters | 52.2% (95% CI: 44.3, 60.1) | 48.1% (95% CI: 41.4, 54.9) |
| Progression of refractive error by greater than −1.00 diopters | 35.7% (95% CI: 28.1, 43.2) | 31.5% (95% CI: 25.2, 37.7) |
| Axial length, mm | 23.62 ± 0.92          | 23.47 ± 1.00          |
| Increase in axial length, mm | 1.01 ± 0.47           | 0.94 ± 0.47           |
| ALCC radius ratio | 3.037 ± 0.116         | 3.010 ± 0.100         |
| Increase in ALCC radius ratio | 0.121 ± 0.065         | 0.113 ± 0.064         |
| **Nonmyopic Children at Baseline** |                             |                        |
| n (nonmyopic children at baseline) | 95 | 142 |
| Refractive error, diopters | -0.45 ± 1.12          | -0.38 ± 1.27          |
| n (becoming myopic during study period) | 50 (52.6%; 95% CI: 42.4, 62.9) | 79 (55.6%; 95% CI: 47.4, 63.9) |
| Change in refractive error, diopters | -0.93 ± 1.05          | -0.86 ± 1.04          |
| Progression of refractive error by greater than −0.00 diopters | 81.1% (95% CI: 73.0, 89.1) | 76.1 (95% CI: 69.0, 83.2) |
| Progression of refractive error by greater than −0.50 diopters | 54.7% (95% CI: 44.5, 64.9) | 54.2% (95% CI: 45.9, 62.5) |
| Progression of refractive error by greater than −1.00 diopters | 31.6% (95% CI: 22.1, 41.1) | 31.7% (95% CI: 23.9, 39.4) |
| Axial length, mm | 23.42 ± 0.85          | 23.40 ± 0.97          |
| Change in axial length, mm | 0.90 ± 0.41           | 0.93 ± 0.44           |
| ALCC radius ratio | 3.003 ± 0.102         | 3.000 ± 0.093         |
| Change in ALCC radius ratio | 0.107 ± 0.058         | 0.111 ± 0.061         |
| **Myopic Children at Baseline** |                             |                        |
| n | 62 | 74 |
| Refractive error, diopters | -1.89 ± 1.85          | -1.28 ± 1.55          |
| Change in refractive error, diopters | -0.97 ± 2.01          | -0.65 ± 1.57          |
| Progression of refractive error by greater than −0.00 diopters | 71.0% (95% CI: 59.4, 82.6) | 56.8% (95% CI: 45.2, 68.3) |
| Progression of refractive error by greater than −0.50 diopters | 48.4% (95% CI: 35.6, 61.1) | 36.5% (95% CI: 25.3, 47.7) |
| Progression of refractive error by greater than −1.00 diopters | 41.9% (95% CI: 29.3, 54.6) | 31.1% (95% CI: 20.3, 41.9) |
| Axial length, mm | 23.93 ± 0.94          | 23.61 ± 1.04          |
| Change in axial length, mm | 1.17 ± 0.50           | 0.95 ± 0.51           |
| ALCC radius ratio | 3.089 ± 0.116         | 3.030 ± 0.111         |
| Change in ALCC radius ratio | 0.143 ± 0.071         | 0.117 ± 0.070         |
Table 4. Extended

| Parameters                                                                 | Estimated Difference or OR | 95% CI          | P Value |
|---------------------------------------------------------------------------|-----------------------------|----------------|---------|
| **Total**                                                                 |                             |                 |         |
| Refractive error in 2016, diopters                                         | 0.33                        | 0.02, 0.64      | 0.04    |
| n (becoming myopic during study period of 4 years)                         | 0.81                        | 0.52, 1.25      | 0.38    |
| Change in refractive error, diopters                                       | 0.15                        | −0.13, 0.44     | 0.28    |
| Progression of refractive error by greater than −0.00 diopters            | −7.6                        | −16.8, 1.6      | 0.10    |
| Progression of refractive error by greater than −0.50 diopters            | −4.1                        | −14.4, 6.3      | 0.44    |
| Progression of refractive error by greater than −1.00 diopters            | −4.2                        | −13.9, 5.5      | 0.40    |
| Axial length, mm                                                           | −0.15                       | −0.35, 0.04     | 0.13    |
| Increase in axial length, mm                                               | 0.07                        | −0.17, 0.03     | 0.16    |
| ALCC radius ratio                                                          | −0.027                      | −0.050, −0.004  | 0.02    |
| Increase in ALCC radius ratio                                              | −0.008                      | −0.022, 0.005   | 0.23    |
| **Nonmyopic Children at Baseline**                                         |                             |                 |         |
| n (nonmyopic children at baseline)                                         |                             |                 |         |
| Refractive error, diopters                                                 | 0.07                        | −0.23, 0.38     | 0.63    |
| n (becoming myopic during study period)                                    | 0.89                        | 0.53, 1.49      | 0.69    |
| Change in refractive error, diopters                                       | 0.06                        | −0.21, 0.34     | 0.65    |
| Progression of refractive error by greater than −0.00 diopters            | 1.35                        | 0.71, 2.56      | 0.42    |
| Progression of refractive error by greater than −0.50 diopters            | 1.02                        | 0.61, 1.72      | 1.00    |
| Progression of refractive error by greater than −1.00 diopters            | 1.00                        | 0.57, 1.74      | 1.00    |
| Axial length, mm                                                           | 0.02                        | −0.25, 0.22     | 0.88    |
| Increase in axial length, mm                                               | 0.03                        | −0.08, 0.15     | 0.57    |
| ALCC radius ratio                                                          | −0.003                      | −0.029, 0.023   | 0.82    |
| Increase in ALCC radius ratio                                              | 0.004                       | −0.012, 0.020   | 0.62    |
| **Myopic Children at Baseline**                                            |                             |                 |         |
| n                                                                        |                             |                 |         |
| Refractive error, diopters                                                 | 0.61                        | 0.02, 1.19      | 0.04    |
| Change in refractive error, diopters                                       | 0.32                        | −0.30, 0.94     | 0.30    |
| Progression of refractive error by greater than −0.00 diopters            | 1.86                        | 0.91, 3.81      | 0.11    |
| Progression of refractive error by greater than −0.50 diopters            | 1.63                        | 0.82, 3.24      | 0.17    |
| Progression of refractive error by greater than −1.00 diopters            | 1.60                        | 0.79, 3.24      | 0.21    |
| Axial length, mm                                                           | −0.33                       | −0.66, 0.01     | 0.056   |
| Change in axial length, mm                                                 | −0.22                       | −0.39, −0.05    | 0.01    |
| ALCC radius ratio                                                          | −0.059                      | −0.098, −0.020  | 0.003   |
| Change in ALCC radius ratio                                                | −0.026                      | −0.050, −0.002  | 0.04    |
Discussion

This school-based longitudinal study compared children of a study group who performed an additional outdoor program that included a jogging exercise for 30 minutes every working day in the school yard during the school break with children of a control group who followed their routine activities. Those children of the study group who were non-myopic at baseline showed a significantly smaller axial elongation and a lower amount of myopization during the first year of follow-up. Such an effect was not observed in the school children of the study group who were already myopic at the baseline of the study. For the first 2 years after the end of the outdoor program, the study group as compared to the control group experienced a more marked axial elongation so that after a total follow-up of 4 years, study group and control group no longer differed significantly in axial length and axial elongation.

The results of our study are in agreement with a large series of observational and mostly cross-sectional investigations on the association between outdoor activities and a decreased prevalence and incidence of myopia.\(^\text{15–21,25–28}\) They confirm previous interventional studies in which an increased amount of time spent outdoors was associated with a lower degree of myopia progression.\(^\text{22–24,29,30}\) As in the study conducted by Wu and associates\(^\text{22}\), a rebound effect could be observed, with a more marked axial elongation taking place in the first 2 years after the end of the outdoor program in the study group as compared to the control group. As consequence, after 4 years of follow-up, the study group and control group no longer differed in axial length and axial elongation. A similar rebound effect was observed in a study observing the change in refractive error in the first year after stopping the nightly application of 1% atropine eye drops for 2 years.\(^\text{31}\) At 1 year after the end of the treatment with atropine, the study group showed higher rates of myopia progression as compared to the control group, which had received placebo eye drops. At 1 year after the end of the atropine application, the absolute amount of myopia was, however, still significantly lower in the study group than in the control group. This result is in contrast to our study in which at 1 year after ending the outdoor program the myopic refractive error did not differ significantly \((P = 0.21)\) between study group and control group and in which the axial length was significantly \((P < 0.001)\) longer in the study group (Table 3).

It has remained unclear why the effect of extended outdoor time on a reduction of myopic progression was observed mainly in nonmyopic children. The finding agrees with the observation made by Wu and colleagues\(^\text{24}\) that the effect of increased outdoor activities on a reduced myopic progression was found...
mainly in children who were not myopic at baseline of the study.\textsuperscript{22} In a second study by Wu and coworkers,\textsuperscript{24} however, children myopic at baseline also showed an effect in association with increased outdoors activities.

The clinical significance of the findings of our study and of the preceding trials on the effect of outdoor activity on the progression of myopia has remained unclear so far.\textsuperscript{22–29,30} In the landmark study by He and colleagues,\textsuperscript{23} the difference in the 3-year change in refractive error between the intervention group and the control group was just 0.17 diopters, indicating a limited clinical significance. In addition, the amount of axial elongation did not vary significantly between the study group and the control group. In our study, the outdoor program of 30 minutes practiced for 1 year also showed only a relatively small effect of 0.05-mm difference in axial elongation or 0.28 diopters in progression of myopic refractive error. Above all, after the end of the program, the effect vanished within 2 years by a rebound effect in the study group. One may discuss whether the 30-minute duration of the program was long enough or whether the program would have had to be continued till puberty—even until the end of adolescence—to achieve a stronger and long-lasting effect.

Potential limitations of our study should be mentioned. First, with only one school selected for each arm of the investigation, the recruitment of the study participants did not occur in a randomized manner. A potential clustering effect could thus not be examined and taken into account. Second, both schools were both located in rural regions, so the possibility of another selection bias exists by not including urban schools. Third, the study sample sizes were relatively small so that a lack of statistical significance might have been caused by a small study sample size. Fourth, refractometry was not performed under cycloplegic conditions so that refractometric measurements might have been influenced by an accommodative effect during the examination. As a consequence, the changes in axial length and the changes in refractive error were not strongly correlated with each other. The main outcome parameter was, however, axial length and axial elongation during the study period, both parameters that were not influenced by the cycloplegic state of the eyes. Fifth, the 1-year jogging program might have changed the outdoor jogging habit in the schoolchildren of the study group after end of the outdoor program, and we did not systematically assess such a change in the jogging habit. This limitation of the study may, however, only serve to strengthen the conclusion of the study, since if the children of the study group had continued jogging, it should have reduced instead of increased the axial elongation in the study group in the first 2 years following the official end of the outdoor program.

In conclusion, an intensified outdoor program for 30 minutes during school breaks had a temporary effect of reducing progression of myopic axial elongation in schoolchildren nonmyopic at baseline. It was followed by a complete rebound effect at 4 years after stopping the program.

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