tvst

https://doi.org/10.1167/tvst.8.3.2

Article

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

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Received: 17 October 2018
Accepted: 22 January 2019
Published: 2 May 2019

Keywords: myopia progression; outdoor activity; myopia prevention; axial elongation; Beijing Children Eye Study

Citation: Guo Y, Liu L, Lv Y, Tang P, Feng Y, Wu M, Xu L, Jonas JB. Outdoor jogging and myopia progression in school children from rural Beijing: the Beijing Children Eye Study. Trans Vis Sci Tech. 2019; 8(3):2, https://doi.org/10.1167/tvst.8.3.2

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

cross-sectional and longitudinal observational studies.[15–21] The number of interventional studies addressing the protective effect of outdoor activities against the development and progression of myopia have been scarce so far.[22–24] In a prospective comparative interventional study performed by Wu and colleagues in Taiwan,[22] 333 out of 571 students participated in an interventional program and spent the school breaks outside of the classrooms. They were additionally encouraged to spend generally more time in the outdoor space. The 238 students of the control group did not have any special programs during the breaks. At the study end at 1 year after baseline, the study group as compared to the control group showed a lower myopic shift ($P = 0.02$) within the subgroup of students who were nonmyopic at baseline. For the children who were myopic at baseline of the study, the study group and the control group did not vary significantly in the progression of myopia.[22] In the landmark study performed by He and colleagues[23] on 6-year-old children in Guangzhou, China, the children of the study group had to stay an additional 40 minutes outdoors at school, while the students of the control group followed their usual activities. The study group as compared to the control group showed a significantly reduced incidence of myopia during a follow-up of 3 years.[23] In another study by Wu and associates,[24] a school-based outdoor promotion program decreased the progression of myopia in both those children who were nonmyopic at baseline and in children who were myopic at baseline of the study. Based on the findings made in these three previous interventional studies, we conducted the present investigation to reassess a potential effect of increased outdoor activity in school children in North China.

Methods

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 noncycloplegic 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 noncycloplegic 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,

Table 1. Baseline Characteristics (Mean ± Standard Deviation) of the Study Group and Control Group

Parameter	Intervention Group ($n = 157$)	Control Group ($n = 216$)	*P* Value
Age, y	6.7 ± 0.7	6.7 ± 0.6	0.69
Girls/boys	81/76	109/107	0.83
Spherical equivalent, diopters	−0.07 ± 1.03	0.11 ± 0.90	0.08
Axial length, mm	22.62 ± 0.73	22.52 ± 0.79	0.24
ALCC	2.92 ± 0.07	2.90 ± 0.07	0.008
Height, cm	124 ± 7	126 ± 7	0.04
Weight, kg	25.2 ± 7.2	26.6 ± 6.8	0.54
Indoor activities, h/day	5.2 ± 1.1	5.1 ± 0.9	0.88
Outdoor activities, h/day	2.3 ± 0.7	2.3 ± 0.8	0.89
Parental myopia	29.3%	23.9%	0.51

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: [(hours spent on a weekday) × 5 + (hours spent on a weekend day) × 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 χ^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 β, 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

Table 2. Extended

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 radius 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

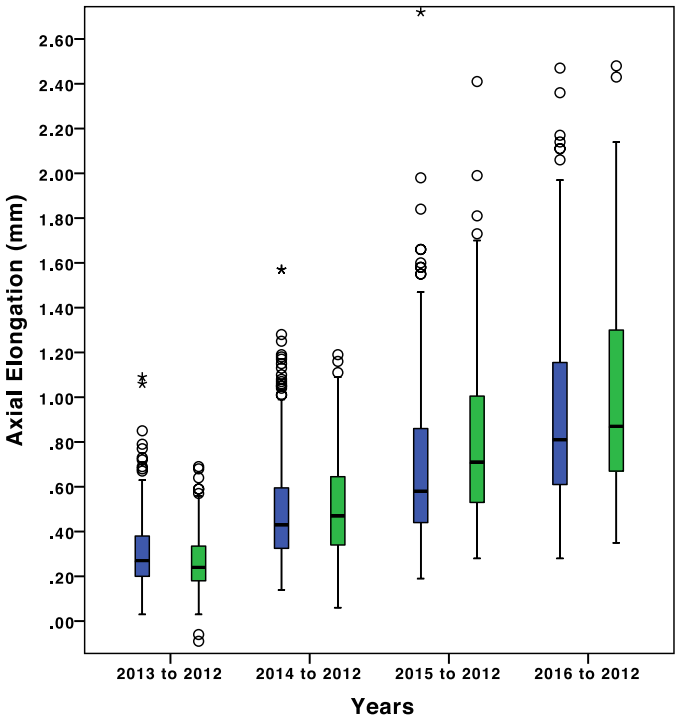

Figure 1. Boxplots showing the distribution of axial elongation in the study group and control group for the study periods from 2013 to 2012, 2014 to 2012, 2015 to 2012, and 2016 to 2012.

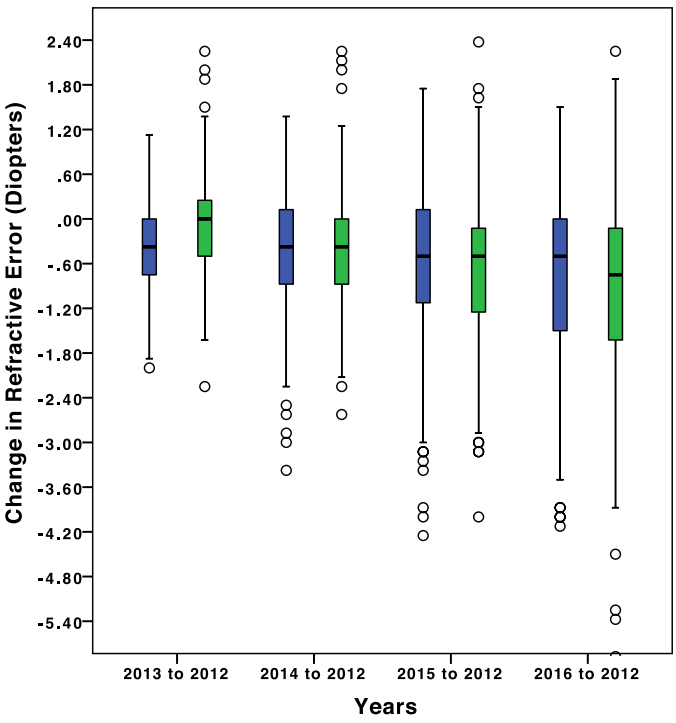

Figure 2. Boxplots showing the distribution of the change in refractive error in the study group and control group for the study periods from 2013 to 2012, 2014 to 2012, 2015 to 2012, and 2016 to 2012.

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 ($P = 0.005$; β: 0.15; B: 0.05; 95% CI: 0.02, 0.09) after adjusting for female sex ($P = 0.03$; β: 0.13; B: 0.05;

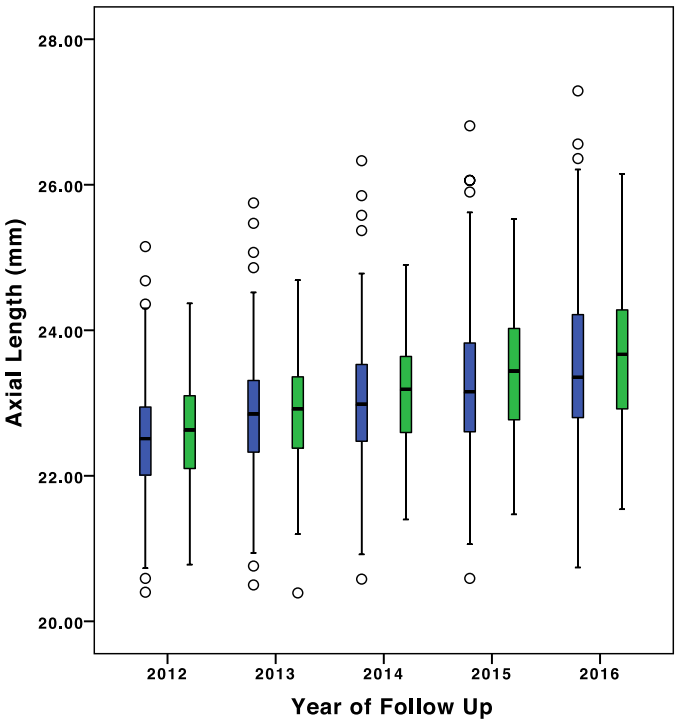

Figure 3. Boxplots showing the distribution of the axial length in the study group and control group, stratified for the study years.

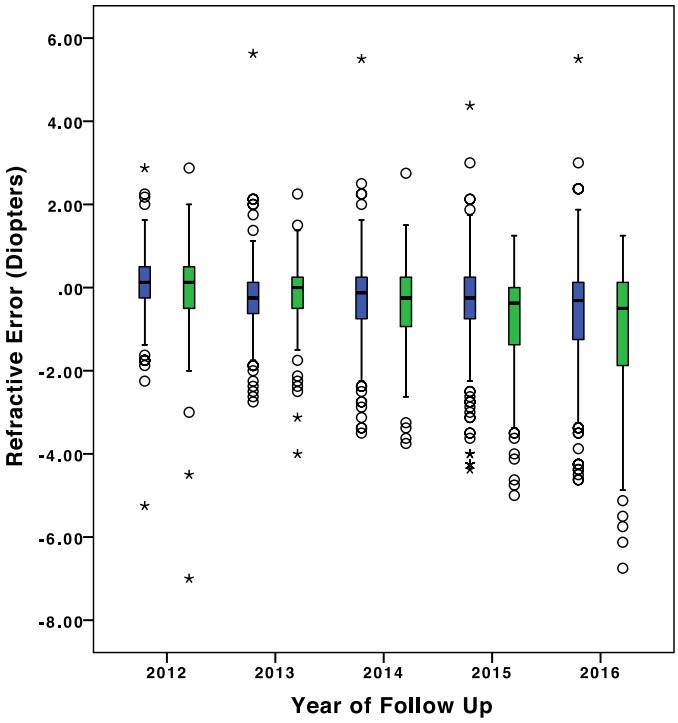

Figure 4. Boxplots showing the distribution of the refractive error in the study group and control group, stratified for the study years.

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 the 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).

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 ± 0.23 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; 0.21 ± 0.23 vs. 0.23 ± 0.35 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 ($P = 0.38$) or for the group of children who were nonmyopic at baseline of the study ($P = 0.69$) (Table 4). In the group of children who were myopic at baseline, the total amount of axial elongation was significantly ($P = 0.01$) larger in the study group.

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 (n = 157)	Control Group (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
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 ± 0.23
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 ± 0.27

Table 3. Extended

Parameters	Estimated Difference or OR	95% CI	*P* Value
Total			
Refractive error, diopters	0.14	−0.08, 0.35	0.21
n (becoming myopic during study period of 2 years)	0.88	0.55, 1.39	0.64
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			
n, nonmyopic children at baseline			
Refractive error, diopters	0.11	−0.11, 0.34	0.36
n (becoming myopic during study period of 2 years)	0.98	0.58, 1.65	1.00
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			
n			
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
Change in axial length, mm	0.03	−0.08, 0.15	0.57
ALCC radius ratio	−0.003	−0.029, 0.023	0.82
Change 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 nonmyopic 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.[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.[22–24,29,30] As in the study conducted by Wu and associates[22] with a 1-year follow-up, we observed the effect of an increased outdoor activities on a reduced myopic progression mainly in children nonmyopic at baseline, while within the subgroup of myopic children at baseline the study group and control group did not differ significantly. It is interesting that in a second study Wu and associates[24] also found an effect in children myopic at baseline. Yi and colleagues[29] performed a school-based trial in Changsha, China, that included 80 schoolchildren age 7 to 11 years. The authors found a reduced myopia progression during a follow-up of 1 year.[29] In the trial performed by Jin and associates,[30] an intervention group of 1735 schoolchildren as compared to a control group of 1316 pupils (age: 6 to 14 years) additionally took part in two outdoor programs of 20 minutes each per day in the school. The study group had a significantly ($P < 0.001$) better uncorrected visual acuity at the end of the 1-year follow-up, and a subgroup undergoing more refined ophthalmological examinations showed a lower incidence of myopia, less axial elongation, and lower amount of myopization. As in Wu's second study, He and colleagues[23] described in their landmark study that the 3-year cumulative incidence of myopia was significantly lower in a study group of children with an addition of 40 minutes of outdoor activity at school versus the control group (30.4% vs. 39.5%; $P < 0.001$). In a similar manner, the 3-year change in refractive error was significantly less for the intervention group than for the control group (−1.42 vs. −1.59 diopters; $P = 0.04$) in He's study. The question arises however, whether the statistically significant difference of 0.17 diopters (95% CI: 0.01, 0.33) had a clinical significance, which may be questionable in view of the small amount of difference and in view of the borderline statistical significance with $P = 0.04$. Correspondingly, the amount of axial elongation did not differ significantly between the study group and the control group (0.95 vs. 0.98 mm; $P = 0.07$). He and colleagues[23] did not differentiate in their analysis between children myopic at baseline and children nonmyopic at baseline.

All these previous interventional studies did not evaluate the further development of myopia and axial length when the outdoor program stopped. In our study, 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.[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[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.[22] In a second study by Wu and coworkers,[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.[22–24,29,30] In the landmark study by He and colleagues,[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.

Acknowledgments

Supported by the National Natural Science Foundation of China (81400431).

Disclosure: **Y. Guo**, None; **L. Liu**, None; **Y. Lv**, None; **P. Tang**, None; **Y. Feng**, None; **M. Wu**, None; **L. Xu**, None; **J.B. Jonas**, (P) patent holder with Biocompatibles UK Ltd., "Treatment of eye diseases using encapsulated cells encoding and secreting neuroprotective factor and/or anti-angiogenic factor," patent number 20120263794; (P), patent application with University of Heidelberg, "Agents for use in the therapeutic or prophylactic treatment of myopia or hyperopia," Europäische Patentanmeldung 15 000 771.4.

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