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# Prevalence of myopia in school children in greater Beijing: the Beijing Childhood Eye Study

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**ABSTRACT.**
***Purpose:*** **To determine the prevalence of myopia in school children in Greater Beijing.**
***Methods:*** **The Beijing Childhood Eye Study was a school-based cross-sectional study. One school of each level (primary, junior high, senior high) was randomly selected from nine randomly selected districts of Greater Beijing. The children underwent non-cycloplegic refractometry and their parents an interview.**
***Results:*** **Of 16 771 eligible students, 15 066 (89.8%) children with a mean age of 13.2 ± 3.4 years (range: 7–18 years) participated. Prevalence of myopia defined as refractive error of ≤−0.50 diopters (D), ≤−1.00 D, ≤−6.00 D and ≤−8.00 D in the right eye was 64.9 ± 0.4%, 53.0 ± 0.4%, 4.3 ± 0.2% and 1.0 ± 0.1% respectively. In multivariate analysis, prevalence of myopia was significantly (p < 0.001) associated with higher age, female gender, urban region and school type. Prevalence of myopia of ≤−1.00 D and of ≤−8.0 D increased from 9.7% and 0% in 7 year olds, respectively, to 74.2% and 1.8% in 17- or 18 year olds respectively. The latter figure was already similar (p = 0.39) to the prevalence of high myopia in the elderly Beijing Eye Study population (1.6%). In a subset of 1082 children undergoing cycloplegia, difference in refractive error between prior to and after cycloplegia was 0.31 ± 0.47 diopters.**
***Conclusions:*** **On the basis of previous investigations from China, our study indicated an ongoing myopic shift in the young generation. Since the prevalence of high myopia in children aged 17 or 18 years was already similar to the one in the elderly Beijing population, the data prognosticate an increase in vision threatening high myopia in the future adult population.**

**Key words:** amblyopia – anisometropia – myopia – myopic shift – refractive error

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## Introduction

The refractive error is one of the principal characteristics of the visual system, and its undercorrection is one of the leading causes of visual impairment worldwide, in particular in children (Resnikoff et al. 2008). Consequently, correction of refractive error is the most cost-effective intervention in public eye health care. An estimated 12.8 million children 5–15 years of age worldwide are affected by undercorrection of refractive error (Zhao et al. 2000; Fan et al. 2004; He et al. 2004, 2007; Robaei et al. 2005; Congdon et al. 2008; Multi-Ethnic Pediatric Eye Disease Study Group 2010; O'Donoghue et al. 2010; Tarczy-Hornoch et al. 2011). Only few population-based studies on the prevalence of myopia and its correction have been performed in China, in particular for the young generation in which a marked myopic shift has been described (Zhao et al. 2000; Fan et al. 2004; He et al. 2004, 2007; Congdon et al. 2008; Xiang et al. 2012a,b). In contrast, the elderly population in China or in other East or South East Asian countries did not differ markedly in the prevalence of myopia as compared to the elderly population in North America (Attebo et al. 1999; Liu et al. 2001; Kempen et al. 2004; Wong et al. 2000; Xu et al. 2005). We therefore conducted the present study to examine the prevalence of myopia in a representative sample of school children in Beijing.

## Methods

The Beijing Childhood Eye Study is a population-based study performed in the region of Greater Beijing and used a stratified cluster sampling technique (You et al. 2012). The ethics committee of the Capital Medical University, the Beijing Municipal Commission of Education and the Beijing Centre for Disease Control and Prevention approved the study, and the parents of the children gave written consent. Informed consent from at least one parent and each child were obtained before examination. The Beijing schools were differentiated into institutions of primary level, junior high level and senior high level. One school from each level was randomly selected from nine randomly selected districts (Xuanwu, Dongcheng, Haidian, Fangshan, Mentougou, Huairou, Changping, Chaoyang and Tongzhou) of 18 districts from the rural region and the urban region of Greater Beijing. Greater Beijing is officially divided into a rural region with agriculture still being the predominant source of income, and the urban region. Fangshan, Mentougou, Changping, Huairou and Tongzhou were considered rural regions, while the Xuanwu, Dongcheng, Haidian and Chaoyang were considered urban regions. All students of the selected schools with an age between 7 and 18 years were invited to participate in the study. The study has been described in detail recently (You et al. 2012). The schools in Beijing were divided into key schools and non-key schools, with pupils at key schools showing higher baseline grades in entry tests and receiving a more intensive education.

All selected students and their parents underwent an oral interview carried out by trained school physicians and the quality of the interview was controlled by disease control officers in each district centre. The interview based on a detailed written questionnaire included questions on general parameters and ocular diseases history, and on reading and working activities, such as the first use of glasses, habits of using glasses, daily activities such as the amount of reading, watching TV, doing school homework and being outdoors, usual distance between the book and the head when reading, and on the occurrence of eye diseases in the family. The detailed analysis of the answers obtained in this interview has recently been presented (You et al. 2012). After the interview, the children underwent an auto refractometry carried out by a senior experienced optometrist. We used an auto refractor (Topcon RM-A7000; Tpocon Co., Tokyo, Japan) and did not apply cycloplegia.

Since involuntary accommodation can influence the refractometric results, a second group of students underwent refractometry before and after cycloplegia in a pilot study. This pilot study group consisted of pupils whose parents were willing their children to undergo cycloplegia. There were no other inclusion or exclusion criteria than as for the general study. Cycloplegia was achieved by 1% cyclopentolate eye drops, given twice within 10 min. If the pupil was not dilated enough (6 mm), a third drop was applied 20 min later. Refractometry was performed about 60 min after the first instillation of the drops. We measured the difference in refractive error before and after cycloplegia, and calculated the prevalence of myopia using the same definitions as for the main study group.

Myopia was defined as refractive error (spherical equivalent) of $\leq -0.50$ diopters, $\leq -1.00$ diopters, $\leq -6.00$ diopters and $\leq -8.00$ diopters, respectively, in the right eye.

Statistical analysis was performed using SPSS for Windows, version 20.0 (IBM-SPSS, Chicago, IL, USA). The prevalence was calculated as the number of participants with the particular type of refractive error in relation to the total number of examined children. Prevalence data were given as mean ± standard error including the 95% confidence intervals (95% CI). The chi-square test was used to compare proportions. Logistic regression was used to compare the prevalence of myopia between age, gender, region habitation (urban versus rural) and school type (key school versus non-key school) groups. Odds ratios (OR) and their 95% CI were presented. All p-values were two-sided and considered statistically significant when <0.05.

# Results

Of 16 771 eligible and invited students, 15 066 [7769 (51.6%) girls] students participated (response rate: 89.8%). Mean age was 13.2 ± 3.4 years (Table 1). Among the study participants, 8860 (58.8%) were living in the rural region of Greater Beijing, and 6206 (41.2%) students were living in the urban region; 5621 (37.3%) children attended the primary school, 4369 (29.0%) students went to the junior high school, and 5076 (33.7%) students attended the senior high school.

The mean refractive error was −1.64 ± 2.18 diopters for the right eyes and −1.46 ± 2.19 diopters for the left eyes (Table 2). It was −1.73 ± 2.34 for the worse eye. Prevalence of myopia defined as refractive error $\leq -0.50$ diopters in the right eye was 64.9 ± 0.4% (95% CI: 64.2, 65.7). Prevalence of myopia defined as refractive error $\leq -1.00$ diopters in the right eye was overall 53.0 ± 0.4% (95% CI: 52.2, 53.8) (Table 3) (Fig. 1).

Prevalence of myopia independently of its definition increased significantly ($p < 0.001$) with age up to an age of 16 years from which onwards the prevalence of myopia was almost constant (Table 2–6) (Figs 1–3). For myopia defined as refractive error $\leq -1.00$ diopters in the right eye, the prevalence increased from 9.7% in the 7-year-old

**Table 1.** Demographic characteristics of the participants of the Beijing Childhood Eye Study.

| Age (years) | *n* (%) | Gender (Boys/girls) (%) | Habitation Urban/rural (%) |
|---|---|---|---|
| 7 | 792 (5.3) | 375/417 (47.3/52.7) | 427/365 (53.9/46.1) |
| 8 | 1172 (7.8) | 589/583 (50.3/49.7) | 628/544 (53.6/46.4) |
| 9 | 1123 (7.5) | 581/542 (51.7/48.3) | 606/519 (54/46) |
| 10 | 1054 (7) | 540/514 (51.2/48.8) | 578/476 (54.8/45.2) |
| 11 | 1005 (6.7) | 493/549 (49.1/50.9) | 456/549 (45.5/54.5) |
| 12 | 457 (3) | 255/202 (55.8/44.2) | 142/315 (31.1/68.9) |
| 13 | 1600 (10.6) | 717/883 (44.8/55.2) | 805/795 (50.3/49.7) |
| 14 | 2058 (13.7) | 1013/1045 (49.2/50.8) | 936/1122 (45.5/54.5) |
| 15 | 731 (4.9) | 378/353 (51.7/48.3) | 305/426 (41.7/58.3) |
| 16 | 1745 (11.6) | 772/973 (44.2/55.8) | 521/1224 (29.9/70.1) |
| 17 | 2051 (13.6) | 942/1109 (45.9/54.1) | 520/1531 (25.4/74.6) |
| 18 | 1278 (8.5) | 642/636 (50.2/49.8) | 282/996 (22.1/77.9) |
| Total | 15 066 (100) | 7297/7769 (48.4/51.6) | 6206/8860 (41.2/58.8) |

children to 43.1% in the 12-year-old children to 72.8% in the 18-year-old teenagers or 74.2% in the combined 17- and 18-year-old group (Table 3). In univariate analysis, girls were significantly ($p < 0.001$) more myopic and more frequently myopic than boys, before and after adjustment for age (Tables 2–6). In univariate analysis, the prevalence of myopia was significantly ($p < 0.001$) associated with older age, female gender, urban region of habitation and type of schools (key schools versus non-key schools).

In multivariate logistic regression analysis, with the presence of myopia (defined as myopic refractive error of ≤−1.00 diopters in the right eye) as dependent parameter and age, gender, region of habitation and type of school as independent variables, the presence of myopia remained significantly (all $p < 0.001$) associated with higher age, female gender, urban region of habitation (urban versus rural) and type of school (key school versus non-key school).

Of 7986 children with myopia (defined as myopic refractive error of ≤−1.00 diopters in the right eye), 4532 (56.7%) wore glasses. The mean age when myopia was detected was 11.7 ± 3.2 years (median: 12 years), and the mean age when glasses were first worn was 12.3 ± 2.9 years (median: 13 years). When myopia was diagnosed, 49.2% of the students chose to use spectacles, 29.1% of the children (or their parents) chose to visit a doctor to confirm the diagnosis and to make sure whether it's possible and how to avoid using spectacles, and 16.0% of the students refused to use spectacles. The children who were willing to wear glasses as compared with the children who chose visiting a doctor or who refused spectacles were significantly older (15.2 ± 2.5 years versus 14.2 ± 3.0 years; $p < 0.001$), were predominantly girls ($p < 0.001$), lived in the urban region ($p = 0.004$) and attended predominantly the key school type ($p < 0.001$).

The distribution of refractive error and the prevalence of myopia as defined by the refractive error of the worse eye were presented in Table 7, stratified by age and gender.

#### High myopia

Prevalence of myopia defined as refractive error ≤−6.00 diopters in the right eye was overall 4.3 ± 0.2% (95% CI: 4.0, 4.7) (Table 4) (Fig. 2). Prevalence of myopia defined as refractive error

**Table 2.** Refractive error (diopters; spherical equivalent) in the Beijing Childhood Eye Study.

| | Right eye | | | | | | Left eye | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Age (years) | *n* (%) | Mean | Median | Standard deviation | Minimum, maximum | 2.5%, 97.5% percentile | Mean | Median | Standard deviation | Minimum, maximum | 2.5%, 97.5% percentile |
| 7 | 792 (5.3) | −0.00 | 0.07 | 0.93 | −5.37, +8.00 | −2.00, +1.26 | 0.15 | 0.24 | 0.92 | −5.06, +8.13 | −1.75, +1.52 |
| 8 | 1172 (7.8) | −0.10 | 0.06 | 1.09 | −6.12, +6.31 | −2.79, +1.66 | 0.00 | 0.12 | 1.12 | −6.69, +8.50 | −2.56, +1.91 |
| 9 | 1123 (7.5) | −0.52 | −0.25 | 1.35 | −8.69, +6.75 | −3.98, +1.37 | −0.37 | −0.13 | 1.39 | −9.25, +8.06 | −3.68, +1.67 |
| 10 | 1054 (7.0) | −0.78 | −0.44 | 1.51 | −11.31, +8.13 | −4.47, +1.07 | −0.69 | −0.31 | 1.54 | −8.44, +8.88 | −4.19, +1.32 |
| 11 | 1005 (6.7) | −1.01 | −0.63 | 1.52 | −9.56, +6.44 | −4.99, +0.88 | −0.87 | −0.50 | 1.57 | −9.06, +5.69 | −5.00, +1.18 |
| 12 | 457 (3.0) | −1.03 | −0.75 | 1.67 | −8.25, +10.06 | −5.00, +1.10 | −0.91 | −0.56 | 1.71 | −9.56, +10.62 | −5.18, +1.03 |
| 13 | 1600 (10.6) | −1.87 | −1.53 | 2.09 | −10.68,+10.18 | −6.50, +0.75 | −1.68 | −1.28 | 2.12 | −10.00,+11.63 | −6.61, +1.24 |
| 14 | 2058 (13.7) | −2.04 | −1.56 | 2.21 | −11.98,+12.18 | −7.03, +0.81 | −1.82 | −1.31 | 2.26 | −11.15,+11.38 | −7.00, +1.31 |
| 15 | 731 (4.9) | −1.87 | −1.63 | 2.23 | −10.25, +12.00 | −6.25, +1.57 | −1.66 | −1.43 | 2.19 | −8.88, +11.82 | −6.10, +1.36 |
| 16 | 1745 (11.6) | −2.55 | −2.25 | 2.29 | −10.31, +11.06 | −7.83,+0.50 | −2.38 | −2.00 | 2.34 | −14.78,+11.06 | −7.87, +0.81 |
| 17 | 2051 (13.6) | −2.66 | −2.43 | 2.34 | −10.38,+11.18 | −7.63, +0.56 | −2.44 | −2.18 | 2.37 | −11.06, +10.69 | −7.66, +1.00 |
| 18 | 1278 (8.5) | −2.52 | −2.18 | 2.44 | −11.44, +12.50 | −7.68, +0.82 | −2.36 | −1.93 | 2.38 | −11.38, +14.00 | −7.75, +0.81 |
| Total | 15 066 (100) | −1.64 | −1.13 | 2.18 | −11.98, +12.5 | −6.81, +1.02 | −1.46 | −0.93 | 2.19 | −14.78, +14.00 | −6.81, +1.25 |

**Table 3.** Prevalence of myopia (defined as refractive error (spherical equivalent) ≤−1.0 diopters in the right eye) stratified by age, gender and region of habitation.

| | Age (years) | | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boys | Total | *n* | 375 | 589 | 581 | 540 | 493 | 255 | 717 | 1013 | 378 | 772 | 942 | 642 |
| | Myopia | *n* | 37 | 76 | 156 | 162 | 176 | 107 | 390 | 573 | 226 | 543 | 673 | 435 |
| | | % | 9.9 | 12.9 | 26.9 | 30 | 35.7 | 42 | 54.4 | 56.6 | 59.8 | 70.3 | 71.4 | 67.8 |
| Girls | Total | *n* | 417 | 583 | 542 | 514 | 512 | 202 | 883 | 1045 | 353 | 973 | 1109 | 636 |
| | Myopia | *n* | 40 | 89 | 153 | 192 | 232 | 90 | 595 | 700 | 250 | 730 | 865 | 496 |
| | | % | 9.6 | 15.3 | 28.2 | 37.4 | 45.3 | 44.6 | 67.4 | 67 | 70.8 | 75 | 78 | 78 |
| Urban | Total | *n* | 427 | 628 | 606 | 578 | 456 | 142 | 805 | 936 | 305 | 521 | 520 | 282 |
| | Myopia | *n* | 50 | 92 | 188 | 214 | 213 | 63 | 552 | 667 | 229 | 419 | 443 | 230 |
| | | % | 11.7 | 14.6 | 31 | 37 | 46.7 | 44.4 | 68.6 | 71.3 | 75.1 | 80.4 | 85.2 | 81.6 |
| Rural | Total | *n* | 365 | 544 | 517 | 476 | 549 | 315 | 795 | 1122 | 426 | 1224 | 1531 | 996 |
| | Myopia | *n* | 27 | 73 | 121 | 140 | 195 | 134 | 433 | 606 | 247 | 854 | 1095 | 701 |
| | | % | 7.4 | 13.4 | 23.4 | 29.4 | 35.5 | 42.5 | 54.5 | 54 | 58 | 69.8 | 71.5 | 70.4 |
| Combined | Total | *n* | 792 | 1172 | 1123 | 1054 | 1005 | 457 | 1600 | 2058 | 731 | 1745 | 2051 | 1278 |
| | Myopia | *n* | 77 | 165 | 309 | 354 | 408 | 197 | 985 | 1273 | 476 | 1273 | 1538 | 931 |
| | | % | 9.7 | 14.1 | 27.5 | 33.6 | 40.6 | 43.1 | 61.6 | 61.9 | 65.1 | 73 | 75 | 72.8 |

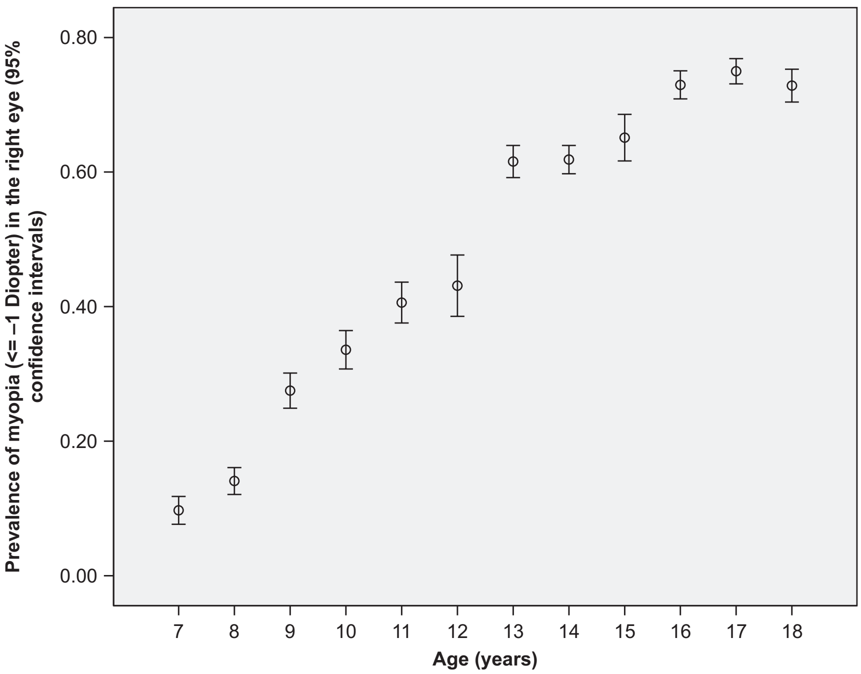


**Fig. 1.** Diagram showing the prevalence of myopia (defined as refractive error ≤−1.0 diopters in the worse eye) in the Beijing Childhood Eye Study.

≤−8.00 diopters in the right eye was overall 1.0 ± 0.1% (Table 5) (Fig. 3). Prevalence of myopia of ≤−1.00 diopters and of ≤−8.0 diopters increased from 9.7% in 7 year olds to 74.2% in children aged 17 or 18 years, and from 0.0% in 7 year olds to 1.8% in children aged 17 or 18 years respectively. Prevalence of high myopia independent of its definition was significantly (all p < 0.001) associated with older age, female gender, urban region of habitation and type of schools (key schools versus non-key schools). In multivariate logistic regression analysis, the presence of myopia (≤−6.00 diopters in the right eye) remained significantly (all p < 0.001) associated with higher age, urban region of habitation (urban versus rural) and type of school (key school versus non-key school). Female gender was marginally associated (p = 0.06). A similar result was obtained if the prevalence of high myopia (defined as myopic refractive error of ≤−8.00 diopters in the right eye) was examined: it was significantly associated with higher age (p < 0.001) and type of school (p < 0.001), while region of habitation (p = 0.24) and gender (p = 0.11) were not significantly associated.

**Pilot study**

The participants of the pilot study were a sub-group of the main study population. The pilot study group included 1082 children (541 (50%) girls) with a mean age of 10.4 ± 2.3 years (median: 10 years; range: 7–18 years). The pilot study group was significantly (p < 0.001) younger than the main study group, while both groups did not vary significantly in gender. Mean refractive error prior to, and after, cycloplegia was −1.60 ± 1.46 diopters and −1.26 ± 1.62 diopters, respectively, in the right eyes, and −1.43 ± 1.50 diopters and −1.12 ± 1.64 diopters, respectively, in the left eyes. The difference in refractive error between the status prior to, and the status after cycloplegia was 0.31 ± 0.47 diopters for the right eyes and it was 0.34 ± 0.46 diopters for the left eyes. The difference between the cycloplegic refractometry and the non-cycloplegic refractometry was not significantly associated with age (p = 0.11 for right eyes; p = 0.13 for left eyes). The difference between pre-cycloplegic values and post-cycloplegic values increased significantly with the pre-cycloplegic hyperopic refractive error (right eyes: correlation coefficient $r = 0.20$; p < 0.001; left eyes: $r = 0.28$; p < 0.001). It was 0.59 ± 0.63 diopters in the range from hyperopia to a myopic refractive error of <−0.50 diopters, and

**Table 4.** Prevalence of myopia (defined as refractive error (spherical equivalent) ≤−6.0 diopters in the right eye) stratified by age, gender and region of habitation.

| | Age (years) | | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boys | Total | *n* | 375 | 589 | 581 | 540 | 493 | 255 | 717 | 1013 | 378 | 772 | 942 | 642 |
| | Myopia | *n* | 0 | 0 | 2 | 8 | 2 | 1 | 24 | 46 | 11 | 54 | 79 | 60 |
| | | % | 0 | 0 | 0.3 | 1.5 | 0.4 | 0.4 | 3.3 | 4.5 | 2.9 | 7 | 8.4 | 6.3 |
| Girls | Total | *n* | 417 | 583 | 542 | 514 | 512 | 202 | 883 | 1045 | 353 | 973 | 1109 | 636 |
| | Myopia | *n* | 0 | 1 | 2 | 3 | 6 | 6 | 36 | 59 | 15 | 82 | 100 | 56 |
| | | % | 0 | 0.2 | 0.4 | 0.6 | 1.2 | 3 | 4.1 | 5.6 | 4.2 | 8.4 | 9 | 8.8 |
| Urban | Total | *n* | 427 | 628 | 606 | 578 | 456 | 142 | 805 | 936 | 305 | 521 | 520 | 282 |
| | Myopia | *n* | 0 | 1 | 2 | 8 | 7 | 2 | 49 | 65 | 15 | 66 | 68 | 36 |
| | | % | 0 | 0.2 | 0.3 | 1.4 | 1.5 | 1.4 | 6.1 | 6.9 | 4.9 | 12.7 | 13.1 | 12.8 |
| Rural | Total | *n* | 365 | 544 | 517 | 476 | 549 | 315 | 795 | 1122 | 426 | 1224 | 1531 | 996 |
| | Myopia | *n* | 0 | 0 | 2 | 3 | 1 | 5 | 11 | 40 | 11 | 70 | 111 | 80 |
| | | % | 0 | 0 | 0.4 | 0.6 | 0.2 | 1.6 | 1.4 | 3.6 | 2.6 | 5.7 | 7.3 | 8 |
| Combined | Total | *n* | 792 | 1172 | 1123 | 1054 | 1005 | 457 | 1600 | 2058 | 731 | 1745 | 2051 | 1278 |
| | Myopia | *n* | 0 | 1 | 4 | 11 | 8 | 7 | 60 | 105 | 26 | 136 | 179 | 116 |
| | | % | 0 | 0.1 | 0.4 | 1 | 0.8 | 1.5 | 3.8 | 5.1 | 3.6 | 7.8 | 8.7 | 9.1 |

**Table 5.** Prevalence of myopia (defined as refractive error (spherical equivalent) ≤−8.0 diopters in the right eye) stratified by age, gender and region of habitation.

| | Age (years) | | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boys | Total | *n* | 375 | 589 | 581 | 540 | 493 | 255 | 717 | 1013 | 378 | 772 | 942 | 642 |
| | Myopia | *n* | 0 | 0 | 0 | 3 | 1 | 1 | 5 | 16 | 1 | 14 | 11 | 1 |
| | | % | 0 | 0 | 0 | 0.6 | 0.2 | 0.4 | 0.7 | 1.6 | 0.3 | 1.8 | 1.2 | 0.2 |
| Girls | Total | *n* | 417 | 583 | 542 | 514 | 512 | 202 | 883 | 1045 | 353 | 973 | 1109 | 636 |
| | Myopia | *n* | 0 | 0 | 1 | 0 | 1 | 0 | 6 | 13 | 4 | 22 | 29 | 12 |
| | | % | 0 | 0 | 0.2 | 0 | 0.2 | 0 | 0.7 | 1.2 | 1.1 | 2.3 | 2.6 | 1.9 |
| Urban | Total | *n* | 427 | 628 | 606 | 578 | 456 | 142 | 805 | 936 | 305 | 521 | 520 | 282 |
| | Myopia | *n* | 0 | 0 | 0 | 1 | 2 | 0 | 9 | 18 | 2 | 20 | 9 | 6 |
| | | % | 0 | 0 | 0 | 0.2 | 0.4 | 0 | 1.1 | 1.9 | 0.7 | 3.8 | 1.7 | 2.1 |
| Rural | Total | *n* | 365 | 544 | 517 | 476 | 549 | 315 | 795 | 1122 | 426 | 1224 | 1531 | 996 |
| | Myopia | *n* | 0 | 0 | 1 | 2 | 0 | 1 | 2 | 11 | 3 | 16 | 31 | 15 |
| | | % | 0 | 0 | 0.2 | 0.4 | 0 | 0.3 | 0.3 | 1 | 0.7 | 1.3 | 2 | 1.5 |
| Combined | Total | *n* | 792 | 1172 | 1123 | 1054 | 1005 | 457 | 1600 | 2058 | 731 | 1745 | 2051 | 1278 |
| | Myopia | *n* | 0 | 0 | 1 | 3 | 2 | 1 | 11 | 29 | 5 | 36 | 40 | 21 |
| | | % | 0 | 0 | 0.1 | 0.3 | 0.2 | 0.2 | 0.7 | 1.4 | 0.7 | 2.1 | 2 | 1.6 |

**Table 6.** Prevalence of myopia (defined as refractive error (spherical equivalent) ≤−1.0 diopters in the right eye) stratified by age, gender and school type.

| | | Age (years) | | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boys | Key school | Total | *n* | 198 | 312 | 305 | 305 | 228 | 87 | 392 | 568 | 205 | 469 | 594 | 421 |
| | | Myopia | *n* | 25 | 44 | 94 | 97 | 91 | 38 | 245 | 399 | 157 | 363 | 455 | 302 |
| | | | % | 12.6 | 14.1 | 30.8 | 31.8 | 39.9 | 43.7 | 62.5 | 70.2 | 76.6 | 77.4 | 76.6 | 71.7 |
| Boys | Common school | Total | *n* | 177 | 277 | 276 | 235 | 265 | 168 | 325 | 445 | 173 | 303 | 348 | 221 |
| | | Myopia | *n* | 12 | 32 | 62 | 65 | 85 | 69 | 145 | 174 | 69 | 180 | 218 | 133 |
| | | | % | 6.8 | 11.6 | 22.5 | 27.7 | 32.1 | 41.1 | 44.6 | 39.1 | 39.9 | 59.4 | 62.6 | 60.2 |
| Girls | Key school | Total | *n* | 229 | 316 | 301 | 274 | 228 | 60 | 524 | 596 | 194 | 642 | 735 | 426 |
| | | Myopia | *n* | 25 | 48 | 94 | 118 | 121 | 28 | 396 | 472 | 162 | 503 | 606 | 347 |
| | | | % | 10.9 | 15.2 | 31.2 | 43.1 | 53.1 | 46.7 | 75.6 | 79.2 | 83.5 | 78.3 | 82.4 | 81.5 |
| Girls | Common school | Total | *n* | 188 | 267 | 241 | 240 | 284 | 142 | 359 | 449 | 159 | 331 | 374 | 210 |
| | | Myopia | *n* | 15 | 41 | 59 | 74 | 111 | 62 | 199 | 228 | 88 | 227 | 259 | 149 |
| | | | % | 8 | 15.4 | 24.5 | 30.8 | 39.1 | 43.7 | 55.4 | 50.8 | 55.3 | 68.6 | 69.3 | 71 |

it was 0.29 ± 0.41 diopters in the eyes with a myopic refractive error of ≥−0.50 diopters. It was 0.48 ± 0.57 diopters in the range from hyperopia to a myopic refractive error of <−1.00 diopters, and it was 0.29 ± 0.41 diopters in the eyes with a myopic refractive error of ≥−1.00 diopters. In the pilot study group, the mean refractive error (after cycloplegia) of the worse eye was −1.34 ± 1.62 diopters. The prevalence of myopia defined as cycloplegic refractive error of <−0.50 diopters, ≤−1.00 diopters and ≤−6.00 diopters, respectively, in the worse eye was 81.1 ± 1.2% (95% CI: 78.8, 83.4), 68.8 ± 1.4% (95% CI: 66.0, 71.5), and 0.8 ± 0.3% (95% CI: 0.3, 1.4).

# Discussion

The data confirm previous studies reporting on a myopic shift in the populations of the metropolitan regions in East Asia, especially for the young generation (Zhao et al. 2000; Fan et al. 2004; He et al. 2004, 2007; Congdon et al. 2008). It is in contrast to other countries in which either no myopic shift or a considerably less marked increase in the prevalence of myopia than in East Asia has been reported (Fledelius 2000; Midelfart et al. 2002; Goldschmidt & Fledelius 2011; Pärssinen 2012). The prevalence of low to medium myopia was markedly higher in the present Beijing Childhood Eye Study than in the (adult) Beijing Eye Study, which included adult Chinese from Greater Beijing with an age of 40+ years (Xu et al. 2005; Jonas et al. 2009). The prevalence of high myopia (defined as refractive error ≤−8.00 diopters) in the 17-year-old children and 18-year-old children in the Beijing Childhood Eye Study was slightly but not statistically significantly higher [1.8 ± 0.2% (Tables 4, 5)] than in the elderly study population of the Beijing Eye Study (1.6 ± 0.2%, p = 0.39). In both study populations, high myopia increased with older age. One may therefore assume that that the prevalence of high myopia in the school children of our present study may further increase when they get older. The myopic shift observed in the young population of the Pacific Rim may therefore lead to an increased prevalence also of high myopia. This is of clinical importance and of importance for public health issues since high myopia is associated with vision threatening diseases such as myopic macular degeneration and myopic chronic open-angle glaucoma (Xu et al. 2007; Jonas et al. 2013). If present population-based studies revealed that myopic macular degeneration already contributed to about

**Table 7.** Refractive error (diopters; spherical equivalent) of the worse eye in the Beijing Childhood Eye Study, stratified by age and gender.

| Age (years) | Total N (%) | ≤−8 D | −8 D</≤−6 D | −6 D</≤−4 D | −4 D</≤−3 D | −3 D</≤−2 D | −2 D</≤−1 D | >−1 D/<+1 D | ≥1 D/<2 D | ≥2 D/<3 D | ≥3 D/<4 D | ≥4 D/<5 D | ≥5 D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Boys* | | | | | | | | | | | | | |
| 7 | 375 (100) | 0 (0) | 0 (0) | 1 (0.3) | 2 (0.5) | 7 (1.9) | 41 (10.9) | 282 (75.2) | 35 (9.3) | 4 (1.1) | 2 (0.5) | 0 (0) | 1 (0.3) |
| 8 | 589 (100) | 0 (0) | 1 (0.2) | 5 (0.8) | 7 (1.2) | 24 (4.1) | 61 (10.4) | 435 (73.9) | 40 (6.8) | 8 (1.4) | 7 (1.2) | 0 (0) | 1 (0.2) |
| 9 | 581 (100) | 0 (0) | 4 (0.7) | 13 (2.2) | 16 (2.8) | 43 (7.4) | 99 (17.0) | 360 (62.0) | 36 (6.2) | 1 (0.2) | 4 (0.7) | 1 (0.2) | 4 (0.7) |
| 10 | 540 (100) | 4 (0.7) | 4 (0.7) | 14 (2.6) | 22 (4.1) | 52 (9.6) | 86 (15.9) | 330 (61.1) | 15 (2.8) | 5 (0.9) | 2 (0.4) | 2 (04) | 4 (0.7) |
| 11 | 493 (100) | 1 (0.2) | 1 (0.2) | 21 (4.3) | 23 (4.7) | 43 (8.7) | 113 (22.9) | 272 (55.2) | 11 (2.2) | 2 (0.4) | 3 (0.6) | 2 (0.4) | 1 (0.2) |
| 12 | 255 (100) | 1 (0.4) | 0 (0) | 7 (2.7) | 15 (5.9) | 29 (11.4) | 58 (22.7) | 133 (52.2) | 9 (3.5) | 0 (0) | 1 (0.4) | 0 (0) | 2 (0.8) |
| 13 | 717 (100) | 8 (1.1) | 21 (2.9) | 76 (10.6) | 73 (10.2) | 109 (15.2) | 133 (18.5) | 271 (37.8) | 13 (1.8) | 2 (0.3) | 3 (0.4) | 1 (0.1) | 7 (1.0) |
| 14 | 1013 (100) | 16 (1.6) | 37 (3.7) | 127 (12.5) | 101 (10.0) | 115 (11.4) | 227 (22.4) | 353 (34.8) | 13 (1.3) | 7 (0.7) | 4 (0.4) | 5 (0.5) | 8 (0.8) |
| 15 | 378 (100) | 3 (0.8) | 13 (3.4) | 44 (11.6) | 39 (10.3) | 49 (13.0) | 89 (23.5) | 123 (32.5) | 7 (1.9) | 1 (0.3) | 1 (0.3) | 2 (0.5) | 7 (1.9) |
| 16 | 772 (100) | 19 (2.5) | 46 (6.0) | 137 (17.7) | 97 (12.6) | 126 (16.3) | 158 (20.5) | 172 (22.3) | 11 (1.4) | 2 (0.3) | 1 (0.1) | 1 (0.1) | 2 (0.3) |
| 17 | 942 (100) | 19 (2.0) | 77 (8.2) | 152 (16.1) | 139 (14.8) | 143 (15.2) | 181 (19.2) | 202 (21.4) | 16 (1.7) | 3 (0.3) | 3 (0.3) | 1 (0.1) | 6 (0.6) |
| 18 | 642 (100) | 12 (1.9) | 60 (9.3) | 87 (13.6) | 79 (12.3) | 89 (13.9) | 132 (20.6) | 164 (25.5) | 9 (1.4) | 3 (0.5) | 3 (0.5) | 0 (0) | 4 (0.6) |
| Total | 7297 (100) | 83 (1.1) | 264 (3.6) | 684 (9.4) | 613 (8.4) | 829 (11.4) | 1378 (18.9) | 3097 (42.4) | 215 (2.9) | 38 (0.5) | 34 (0.4) | 15 (0.2) | 47 (0.6) |
| *Girls* | | | | | | | | | | | | | |
| 7 | 417 (100) | 0 (0) | 0 (0) | 1 (0.2) | 1 (0.2) | 11 (2.6) | 39 (9.4) | 330 (79.1) | 26 (6.2) | 5 (1.2) | 1 (0.2) | 1 (0.2) | 2 (0.5) |
| 8 | 583 (100) | 0 (0) | 2 (0.3) | 1 (0.2) | 10 (1.7) | 25 (4.3) | 69 (11.8) | 411 (70.5) | 49 (8.4) | 6 (1.0) | 5 (0.9) | 1 (0.2) | 4 (0.7) |
| 9 | 542 (100) | 2 (0.4) | 1 (0.2) | 9 (1.7) | 17 (3.1) | 40 (7.4) | 100 (18.5) | 337 (62.2) | 25 (4.6) | 5 (0.9) | 3 (0.6) | 0 (0) | 3 (0.6) |
| 10 | 514 (100) | 0 (0) | 3 (0.6) | 17 (3.3) | 32 (6.2) | 57 (11.1) | 104 (20.2) | 278 (54.1) | 15 (2.9) | 2 (0.4) | 2 (0.4) | 1 (0.2) | 3 (0.6) |
| 11 | 512 (100) | 1 (0.2) | 6 (1.2) | 32 (6.3) | 38 (7.4) | 57 (11.1) | 125 (24.4) | 235 (45.9) | 8 (1.6) | 4 (0.8) | 4 (0.8) | 1 (0.2) | 1 (0.2) |
| 12 | 202 (100) | 1 (0.5) | 5 (2.5) | 14 (6.9) | 11 (5.4) | 22 (10.9) | 45 (22.3) | 95 (47.0) | 5 (2.5) | 1 (0.5) | 2 (1.0) | 0 (0) | 1 (0.5) |
| 13 | 883 (100) | 7 (0.8) | 36 (4.1) | 110 (12.6) | 111 (12.6) | 151 (17.1) | 217 (24.6) | 227 (25.7) | 8 (0.9) | 8 (0.9) | 2 (0.2) | 1 (0.1) | 4 (0.5) |
| 14 | 1045 (100) | 14 (1.3) | 59 (5.6) | 153 (14.6) | 127 (12.2) | 185 (17.7) | 200 (19.1) | 272 (26.0) | 16 (1.5) | 6 (0.6) | 3 (0.3) | 5 (0.5) | 5 (0.5) |
| 15 | 353 (100) | 4 (1.1) | 14 (4.0) | 48 (13.6) | 48 (13.6) | 71 (20.1) | 70 (19.8) | 87 (24.6) | 2 (0.6) | 1 (0.3) | 2 (0.6) | 1 (0.3) | 5 (1.4) |
| 16 | 973 (100) | 30 (3.1) | 67 (6.9) | 171 (17.6) | 148 (15.2) | 167 (17.2) | 188 (19.3) | 183 (18.8) | 7 (0.7) | 3 (0.3) | 1 (0.1) | 2 (0.2) | 6 (0.6) |
| 17 | 1109 (100) | 34 (3.1) | 84 (7.6) | 218 (19.7) | 174 (15.7) | 200 (18.0) | 201 (18.1) | 164 (14.8) | 14 (1.3) | 6 (0.5) | 3 (0.3) | 3 (0.3) | 8 (0.7) |
| 18 | 636 (100) | 15 (2.4) | 52 (8.2) | 108 (17.0) | 99 (15.6) | 116 (18.2) | 136 (21.4) | 94 (14.8) | 4 (0.6) | 4 (0.6) | 1 (0.2) | 1 (0.2) | 6 (0.9) |
| Total | 7769 (100) | 108 (1.4) | 329 (4.2) | 882 (11.4) | 816 (10.5) | 1100 (14.2) | 1495 (19.2) | 2706 (34.8) | 183 (2.4) | 51 (0.7) | 31 (0.4) | 19 (0.2) | 49 (0.6) |

25% of visual impairment in adult Chinese (Liu et al. 2001), this figure is expected to increase in future.

Comparing the prevalence of myopia in this study with the figures obtained in previous childhood studies from China (Zhao et al. 2000; Fan et al. 2004; He et al. 2004, 2007; Congdon et al. 2008) shows varying results. The study best comparable with the Beijing Childhood Eye Study is the study by He et al. (2004) from Guangzhou in Southern China. Examining 4364 children aged 5–15 years in the year 2004, He et al. found a prevalence of myopia of 3.3% in children aged 5 years, and of 73.1% in the children aged 15 years. These figures are similar to the data found in our study population. In a study by Fan et al. (2004) from Hong Kong, a total of 7560 children aged 5–16 years were examined with cycloplegic autorefractometry in the year 2004. Mean spherical equivalent refraction was $-0.33 \pm 11.56$ diopters. Myopia defined as myopic refractive error $\leq -0.50$ diopters was found in $36.7 \pm 2.9\%$ of children. These figures are lower than the data in our study population. It is has remained unclear, however, whether the difference between studies was due to the lack of cycloplegia performed in our study, or whether it indicates an increase in the prevalence of myopia over the years. In other studies from other regions China, lower myopia prevalence was reported. In 1998, the Refractive Error Studies in Children was conducted in the rural Shunyi District northeast of Beijing on randomly selected 5884 children aged 5–15 years (Zhao et al. 2000). Myopia was essentially absent in the 5-year-old children, and the prevalence of myopia increased to 36.7% in boys and to 55.0% in girls by the age of 15 years. The overall prevalence myopia was 16.7%. In 2005, a similar study was carried out in the southern rural county of Yangxi. It included 2454 children with an age of 13–17 years. The prevalence of myopia increased from 36.8% in the 13-year-old children to 53.9% in the 17-year-old teenagers. Pi et al. (2010) conducted a population-based refractive error study in Chongqing in West China. They found a prevalence of myopia increasing from 0.42% in 6-year-old children to 27.11% in 15-year-old subjects. The lower prevalence in these studies from Shunyi, Yangxi and Chongqing may indicate that the prevalence of myopia is not always high in China, but that it

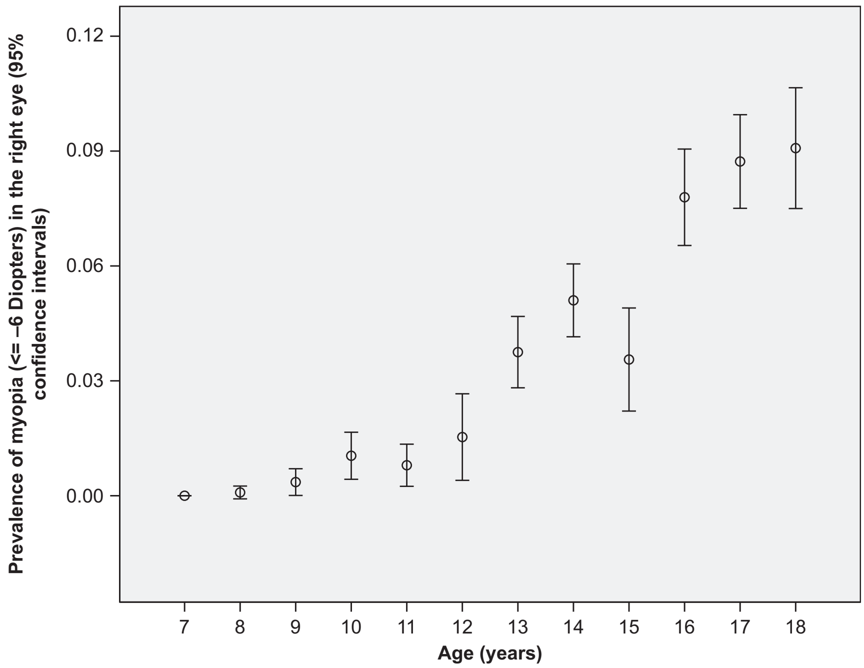


**Fig. 2.** Diagram showing the prevalence of myopia (defined as refractive error ≤−6.0 diopters in the worse eye) in the Beijing Childhood Eye Study.

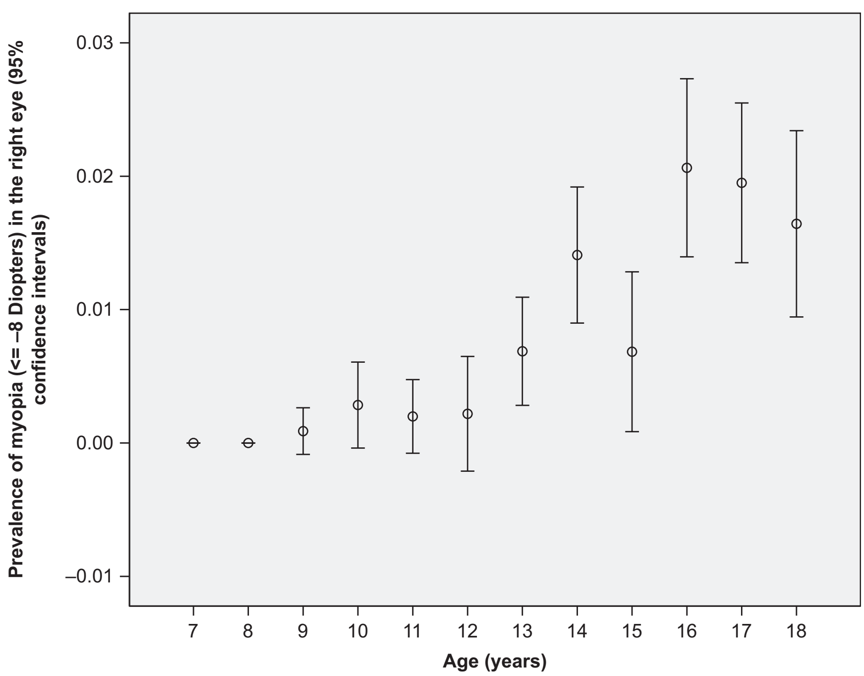


**Fig. 3.** Diagram showing the prevalence of myopia (defined as refractive error ≤−8.0 diopters in the worse eye) in the Beijing Childhood Eye Study.

depends on the degree of development of the region studied. Our finding of high prevalence of myopia in the 18-year-old group agrees with a recent study from South Korea, in which the 19-year-old male population in Seoul, Korea, demonstrated a high myopic prevalence of 96.5% (Jung et al. 2012). In that study, refractometry was performed under cycloplegic conditions, so that our study without cycloplegia and the investigation from South Korea with cycloplegia arrive at similar results. Our study also agrees with a recent cross-sectional study on 5083 students from Donghua University in Shanghai (Sun et al. 2012). The mean refractive error was −4.1 diopters, and of the subjects 95.5% were myopic (<−0.50 diopters), 19.5% were highly myopic (<−6.0 diopters) and only 3.3% were emmetropic (−0.5 diopters to +0.5 diopters). Furthermore, the tendency towards more myopia is also shown in the recent investigation by Xiang et al. (2012b) who showed that the prevalence of myopia was significantly higher in Chinese children than in their parents.

The question arises on the possible causes and mechanisms of the increasing prevalence in myopia in Asia, and why this does not hold true in Western countries. Recent studies have indicated that the development of myopia strongly depends on the amount of time spent outdoors versus indoors. To cite examples, Rose et al. (2008a,b) reported that a lower prevalence of myopia in Chinese children raised in Sydney as compared to Chinese children living in Singapore was associated with increased hours of outdoor activities. Rose et al. were also the first to separate the effects of being outdoors and being physically active on the association with myopia. Rose et al. additionally hypothesized that the early educational pressures found in Singapore but not in Sydney was another factor contributing to the differences in the prevalence of myopia between Chinese children from Sydney versus Singapore. The investigation by Rose et al. was supported by an investigation of Guggenheim et al. (2012) who found that both less time spent outdoors and less physical activity were associated with incident myopia, with time outdoors having the larger effect. Guggenheim et al. concluded that time spent outdoors was predictive of incident myopia independently of the physical activity level. Mutti et al. (2002) reported a protective effect of outdoor activities against myopia, in both a cross-sectional study and a longitudinal study (Jones et al. 2007). It also agrees with the recent study by Jones-Jordan et al.(2011) who found that before the onset of myopia, near work activities of future myopic children did not differ from those children who remained emmetropic. Those children who became myopic had fewer outdoor/sports activity hours than the remaining emmetropic children before, at, and after myopia onset. Summarizing these findings, one may argue that the differences in lifestyle including outdoor activity, educational pressure and cultural aspects between children raised in Beijing and children educated in Western countries may be some of the reasons for the differences in the myopia prevalence between both groups.

Of particular interest in our study may be the prevalence of high myopia since high myopia, usually with a myopic refractive error of more than −6 diopters or −8 diopters (Xu et al. 2010), is associated with myopic changes in the macula and optic nerve head. High myopia may also be particularly interesting in our study since it is likely that the errors in estimation of high myopia as compared to the errors in the assessment of minor myopia will be small without cycloplegia. The prevalence of high myopia defined as refractive error ≤−6.00 diopters was overall 4.3 ± 0.2% (Table 4) (Fig. 2), and its prevalence increased from 0.0% in 7 year olds to 8.9% in children aged 17 or 18 years respectively. The prevalence of myopia defined as refractive error ≤−8.00 diopters was overall 1.0 ± 0.1% (Table 5) (Fig. 3), and its prevalence increased from 0.0% in 7 year olds to 1.8% in children aged 17 or 18 years respectively. Corresponding to the association between the prevalence of high myopia and age, the prevalence of high myopia in our 17- and 18-years-old study participants was lower than in the university students examination from Shanghai, where 19.5% of the study population were highly myopic (<−6.0 diopters) (Sun et al. 2012). It may suggest an ongoing shift, in particular in the prevalence of high myopia, in East Asia. Considering the ongoing urbanization and the association between myopia and urban region of habitation, one may predict a further increase in the prevalence of myopia in China. It is also suggested by the comparison of our figures with the figures on high myopia from South Korea with a prevalence of high myopia of 21.61% (Jung et al. 2012).

As has recently been shown (You et al. 2012), it may also be of interest that the prevalence of myopia in general, and the prevalence of high myopia in particular, were associated with key schools, after adjusting for age, region of habitation and gender. It may again point towards an association between the development of myopia and the lifestyle including the time of spent outdoors versus indoors.

The main limitation of our study was that cycloplegia was not performed in the main study. This might lead to over-estimation of myopia and under-estimation of hyperopia due to accommodation. In the pilot study group using cycloplegic refractometry, the difference in refractive error prior to, and after cycloplegia was about 0.3 diopters. The difference increased significantly with the pre-cycloplegic hyperopic refractive error, so that the prevalence figures of hyperopia were underestimated to a greater amount than the prevalence figures for myopia were overestimated. This result agrees with a recent study by Fotouhi et al. (2012). In the eyes with a myopic refractive error of more than −0.50 diopters, the difference between the pre-cycloplegic measurements and the cycloplegic measurements was 0.29 ± 0.40 diopters. The prevalence of myopia (defined as cycloplegic refractive error <−0.50 diopters in the worse eye) was 81.1 ± 1.2% (95% CI: 78.8, 83.4) in the pilot study group, and the prevalence of myopia (defined as cycloplegic refractive error ≤−1.00 diopters in the worse eye) was 68.8 ± 1.4% (95% CI: 66.0, 71.5) in the pilot study group. These figures were similar to, or even higher than, the values obtained in the main study population without cycloplegia. This effect was, however, likely to a selection artefact since it may have been probable that patients of children with known myopia were more easily willing to let their children undergo cycloplegia as compared to parents of emmetropic children. At the bottom line, the prevalence figures of myopia in the main study population will have to be reduced since the lack of cycloplegia will have slightly and falsely elevated the prevalence figures of myopia.

In conclusion, our study showed an ongoing myopic shift in the young generation of mainland China, with a higher prevalence of myopia in school children from Beijing examined in 2008 than in studies carried out in the period 10 years earlier. Since the prevalence of high myopia was higher in children aged 17 or 18 years than in the elderly population of Beijing, the data prognosticate an increase in vision threatening high myopia in the future adult population.

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