Generational difference of refractive error in the baseline study of the Beijing Myopia Progression Study

Yuan Bo Liang,1,2,3 Zhong Lin1,3 Balamurali Vasudevan,5 Vishal Jhanji,3 Alvin Young,4 Tie Ying Gao,6,3 Shi Song Rong,3 Ning Li Wang,1 Kenneth J Ciuffreda7

ABSTRACT
Aims To report the refractive error difference (RED) between parents and their children and the estimated single generational myopic shift in an urban area in China.
Methods 395 children aged 6–17 years and their parents, who had been enrolled in the Beijing Myopia Progression Study were included. Cycloplegic and non-cycloplegic refraction of the children and parents were performed, respectively. RED was defined as the difference between the average parental spherical equivalent (SE) and the average SE of their children. Binominal fitted curves of RED were plotted as a function of the children’s age. Generational myopic shift was defined as the estimated RED according to the prediction model at the age of 18 years.
Results 395 families were enrolled. The RED was positively correlated with the children’s age (rparent = 0.58, p < 0.001). The RED (median (25th and 75th percentile)) was −1.18 (−3.23 to −1.00) dioptres (D) in children at 6.0–7.9 years of age, and it increased to 1.53 (−0.12 to 3.44) D in children at 16.0–17.9 years of age. The SE of the children approached the average SE of their parents at the age of 11 years. At the age of 18 years, the children’s estimated myopic shift would be up to 1.94 D.
Conclusions In this sample, children’s refractive errors at the age of 11 years were already similar to their parents. Moreover, the estimated myopia in children at the age of 18 years would be up to 2.0 D higher than their parents. This remarkable single-generation myopic shift indicates that there are likely effects of environmental factors on myopia development in urban Chinese children.

INTRODUCTION
Myopia in school children is a critical public health problem in rural and urban populations in East Asia.1–4 Epidemiological studies have identified parental history of myopia as a significant risk factor for both the onset and progression of myopia in children.3–7 The odds of children born to two parents with myopia becoming myopic are approximately six times greater than in children with only one or no parent with myopia.5 However, few studies have reported the quantitative relation between refractive errors in parents and their children.

In addition to the genetic risk factors, environment factors also play an important role in the development of myopia.8–10 Prevalence of myopia in the Chinese adult (40 years or older) population in urban (Beijing) or rural area (Handan) is approximately 20%.11,12 The similarity in prevalence of myopia among adults suggests that environmental or lifestyle determinants for myopia may be likely similar in the older members of the Chinese population living in urban and rural settings. The overall increasing prevalence of myopia in the younger population in China, and the significantly higher prevalence of myopia in urban children (eg, 78.4% in 15-year-old children in Guangzhou) as compared with rural ones (eg, 43.0% in 15-year-old children in Yangxi, a rural country located in the west of Guangzhou),13 implied that the lifestyle and exposure to environmental factors are different in the younger generation.13 Epidemiological studies found a remarkable increasing trend in the prevalence of myopia in the same area decades later in children14–16 and adults,17 which provides strong evidence for the importance of environmental factors on the development of myopia.

Besides the re-evaluation of prevalence of myopia decades later, the generational myopic shift from parents to their children, who share extremely similar genetic factors, would be of great importance as it would reflect the environmental effects on the development of myopia in a relatively short span of time. In the Beijing Myopia Progression Study (BMPS), details of the refractive error in the majority of the parents had been obtained. Thus, in this present report, we describe the quantitative, age-specific refractive error differences (REDs) from parents to their children.

METHODS
Subjects
The BMPS is a 3-year, hospital-based, cohort study that primarily aims to investigate the possible relationship between near-work-induced transient myopia and permanent myopia. The study followed the tenets of the Declaration of Helsinki and was approved by the ethics committee of the Beijing Tongren Hospital. All participants (children and their parents) signed a written informed consent. Details of the study design, sample size estimation and baseline characteristics of BMPS have been reported elsewhere.18

The criteria for recruitment included: (1) children from elite primary or secondary schools in Beijing aged 6–17 years; (2) best-corrected visual acuity 0.1 or better (log minimum angle of resolution, LogMAR); and (3) children who were able to cooperate and return for scheduled visits. The exclusion criteria were: (1) presence of amblyopia and/or strabismus; (2) history of intracocular
surgery or penetrating ocular trauma; (3) severe medical or ocular health problems or mental disease. The parents of these children were also invited to join the study. The participants (both children and their parents) received comprehensive vision examinations and a detailed questionnaire related to their health and daily habits.

**Refractive error**

Cycloplegic refraction of each eye was performed in all children after instilling three drops of cyclopentolate 1% (Cyclogyl, Alcon, Fort Worth, Dallas, USA), whereas a non-cycloplegic refraction was performed for the parents (Accuref-K9001, Shin-Nippon, Japan). Preoperative refractive error was used in 13 parents who had previously undergone refractive surgery. Besides refractive surgery, no intraocular surgery history or other ocular diseases that could have impacted the refractive error were found for the parents who visited the clinical centre. About 186 (23.5%, 186/790) parental refractive error readings (138 fathers and 48 mothers) were obtained by self-report through a telephone call, as they could not visit the clinical centre.

**Definitions**

Children’s refractive error was defined as the average of the cycloplegic spherical equivalent (SE, sphere+1/2 cylinder) of both eyes combined. Parental refractive error was defined as the average of non-cycloplegic SE of the father and the mother (four eyes), as the influence of either parent remains unknown. Myopia and high myopia were defined as, respectively, SE ≤ −0.50 D and SE ≤ −6.0 D. The RED was defined as the difference in the refractive error of the parents and their children, that is, parental SE minus children’s SE.

**Data analysis**

Data with either a normal or non-normal distribution were presented as the mean±1 SD and the median (25th and 75th percentile), respectively. Spearman’s correlation between RED and the children’s age was performed. Statistical significance was determined using the rank-sum test (non-normal distribution). The χ² test was used to assess the statistical significance of the categorical data.

As the number of subjects in some age subgroups (ie, children aged 6, 15 or 17 years) was less than 20, adjacent age groups were combined. The RED of each family was calculated, and then averaged in each age group. The median RED and proportion of children with a higher myopic SE than their parents as a function of the children’s combined age were calculated. Binomial curves with RED/the proportion of higher myopic SE of children than their parents as dependent variable, and the children’s combined age as independent variable, were fitted to investigate the trend of RED/the higher myopic proportion. Binomial curve fitting was performed for RED and children’s age, as it showed the highest R² value among several comprehensive curve fitting methods (eg, linear, logarithmic curve fitting). Generational myopic shift was defined as the estimated RED according to the fitted curve at the age of 18 years because the age of myopia stabilisation in the majority of children was reported to be less than 18 years.¹⁹

Statistical analysis was performed with Statistical Analysis System for Windows V9.1.3 (SAS Inc., Cary, North Carolina, USA). A p value less than 0.05 was considered to be statistically significant.

**RESULTS**

A total of 395 families (each consisting of one child and two parents) with complete refractive error data were enrolled in this study including 187 boys and 208 girls. The mean (±SD) age of the children was 10.4±3.1 years (range from 6 to 17 years). Figure 1 showed the distribution of refractive error in children of all ages and their parents (figure 1A, skewness was −0.04 and −0.70 for children and parents, respectively), in
Table 1  Characteristics of children and parents included in this study

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of children (M : F)</td>
<td>187 : 208</td>
</tr>
<tr>
<td>Age (mean±SD, years)</td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>10.4±3.1</td>
</tr>
<tr>
<td>Fathers</td>
<td>41.4±4.6</td>
</tr>
<tr>
<td>Mothers</td>
<td>39.1±4.0</td>
</tr>
<tr>
<td>Spherical equivalent (median (25th and 75th percentiles), dioptres)</td>
<td></td>
</tr>
<tr>
<td>Children*</td>
<td>−1.44 (−3.13 to 0.38)</td>
</tr>
<tr>
<td>Fathers*</td>
<td>−1.00 (−3.50 to 0.00)</td>
</tr>
<tr>
<td>Mothers*</td>
<td>−1.09 (−3.56 to −0.25)</td>
</tr>
<tr>
<td>Parents†</td>
<td>−1.69 (−3.22 to −0.50)</td>
</tr>
<tr>
<td>Myopia (n, %)†</td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>264 (66.8)</td>
</tr>
<tr>
<td>Fathers</td>
<td>238 (60.3)</td>
</tr>
<tr>
<td>Mothers</td>
<td>271 (68.6)</td>
</tr>
<tr>
<td>High myopia (n, %)†</td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>17 (4.3)</td>
</tr>
<tr>
<td>Fathers</td>
<td>26 (6.6)</td>
</tr>
<tr>
<td>Mothers</td>
<td>45 (11.4)</td>
</tr>
<tr>
<td>Parents with myopia (n, %)†</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>63 (16.0)</td>
</tr>
<tr>
<td>One</td>
<td>155 (39.2)</td>
</tr>
<tr>
<td>Both</td>
<td>177 (44.8)</td>
</tr>
</tbody>
</table>

*Refractive error was defined as the average spherical equivalent of both eyes.
†Refractive error was defined as the average spherical equivalent of father and mother.
‡Myopia was defined as SE less than/equal to −0.50 D; high myopia as SE less than/equal to −6.0 D.
§Significant difference compared with that in children, using χ² test.

DISCUSSION

To the best of our knowledge, this is the first study to describe the quantitatively refractive error shift from parents to children, over a relatively wide age range of children. Wu et al. reported that the prevalence of myopia increased from 5.8% in the grandparents’ generation to 20.8% in the parents’ generation, and then further to 26.2% in the children’s generation in China, suggesting a considerable environmental effect on myopia development over this relatively short time span. Although the data spanned through three generations with a very large sample size (n>3000) and wide age range (7–17 years), only the children’s non-cycloplegic refractive error, and the parents and grandparents binary refractive error state (myopia or not), were obtained. Hence, the important

Table 2  Number and refractive error of children and parents

<table>
<thead>
<tr>
<th>Children’s age (years)</th>
<th>Number</th>
<th>Refractive error (dioptres)†</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Children</td>
<td>Parents</td>
</tr>
<tr>
<td>6.0–7.9</td>
<td>92</td>
<td>0.22 (−1.20 to 1.06)</td>
<td>−1.77 (−2.98 to −0.47)</td>
</tr>
<tr>
<td>8.0–9.9</td>
<td>107</td>
<td>−0.56 (−1.94 to −0.88)</td>
<td>−2.00 (−3.34 to −0.69)</td>
</tr>
<tr>
<td>10.0–11.9</td>
<td>30</td>
<td>−2.56 (−3.88 to −1.44)</td>
<td>−2.00 (−3.78 to −0.94)</td>
</tr>
<tr>
<td>12.0–13.9</td>
<td>103</td>
<td>−2.69 (−4.06 to −1.31)</td>
<td>−1.89 (−3.22 to −0.50)</td>
</tr>
<tr>
<td>14.0–15.9</td>
<td>23</td>
<td>−2.94 (−4.00 to −1.25)</td>
<td>−0.59 (−1.88 to 0.00)</td>
</tr>
<tr>
<td>16.0–17.9</td>
<td>40</td>
<td>−2.59 (−5.19 to −1.47)</td>
<td>−1.05 (−2.58 to −0.23)</td>
</tr>
</tbody>
</table>

* p Value: using rank-sum test.
†Children’s refractive error was defined as the average spherical equivalent of both eyes; parental refractive error was defined as the average spherical equivalent of father and mother, presented as median (25th and 75th percentile).

quantitative changes over the generations remain unknown. Three epidemiological studies reported the prevalence of myopia in urban children in China.\textsuperscript{1, 2} The population-based prevalence of myopia increased from 5.9% at the age of 6 years, to 78.4% at the age of 15 years, in urban children of South China.\textsuperscript{1} The school-based prevalence of myopia increased from 28.9% at the age of 7 years, to 48.2% at the age of 10 years, and further to 53.1% at the age of 11 years or more in Hong Kong students.\textsuperscript{21} A recent survey on self-reported prevalence of myopia in children aged 12–19 years in Taiwan was 70.3%.\textsuperscript{4} The prevalence of myopia in the current study also increased from 39.3% at the age of 7 years, to 68.8% at the age of 10 years, and further to 89.4% at the age of 11–17 years. However, our study provides the crucial quantitative shift of refractive error in children when compared with their parents. Thus, due to the increased environmental demands (such as more near-work or less time outdoors) at age 11 years, the children would have already attained the level of myopia of their parents and furthermore, have gone even beyond that as discussed below as per the estimated model findings. We believe that it is very significant to predict the development of myopia in children at different ages, as well as the myopic shift between generations, for example, for public health management and for development of preventive measures.

There were several important findings in our study. First, with regard to the overall age range (6–17 years), the RED and the proportion of children who had a higher myopic refractive error compared with their parents, increased with the age of children. Second, by using the estimated model at the age of 11 years, the children’s SE would be close to the average SE of their parents; and furthermore, half of the children would have a higher myopic refractive error than their parents. Third, by using the estimated model, the children’s myopic shift and their chances of having higher myopia compared with their parents at the age of 18 years would be nearly 2.0 D and 80%, respectively. To some extent, this noticeable myopic shift found in only a span of two generations reflects an additional effect of an environmental change (such as exposure to more intensive near-work, educational attainment and less time outdoors).\textsuperscript{22–24}

The generational myopic shift described and quantified in our study supports a predominant, although not necessarily exclusive, environmental effect on the increasing prevalence of myopia over the two generations.\textsuperscript{14, 15} Indeed, previous longitudinal studies showed a predominant hyperopic shift,\textsuperscript{23, 26} that is, a physiological decrease in the prevalence of myopia with age, among adults aged 40–60 years.\textsuperscript{27} This was principally explained by a change in the crystalline lens with age.\textsuperscript{28} However, a longitudinal clinical observation of simple myopia (SE ranged from −1.0 to −6.0 D) for more than 20 years showed an average myopic shift of −0.60 D, −0.39 D and −0.29 D during the third (20–29 years, and so on), fourth and fifth decades, respectively; and a hyperopic shift of +0.28 D and +0.41 D during the sixth and seventh decades, respectively.\textsuperscript{29} The myopic shift among adults younger than 45 years suggested that a decrease in the prevalence of myopia is unlikely due to physiological decrease in the ocular biometric parameters; although further direct evidence of the ocular parameters is warranted. Furthermore, the final stable myopic level was supposed to be consistent over two generations if and only if a physiological effect exists. As the time spent on reading and time outdoors were associated with longer ocular length and refractive change towards myopia,\textsuperscript{22–24} we conclude that environmental factors, such as near-work and time outdoors, play an important role in this generational myopic progression.

Although our study provides interesting findings, the representativeness of RED in this study may be limited because the participants in the BMPS were not selected randomly. The median (mean) refractive error was 0.00 (−1.01) D in an urban Beijing population aged 40–44 years,\textsuperscript{11} which was clearly more hyperopic than that of the parents (median −1.69 D; mean −2.03 D) in a similar age group in the current study. We enrolled children through flyers provided to the schools and our hospital. As most of the children were driven to participate in this study by their parents, it was possible that parents with higher myopia, higher socioeconomic status and/or higher educational attainment were more likely to join the study, and thus the generational myopic shift may have been underestimated. Furthermore, the mean non-cycloplegic SE would be approximately 0.4 D more myopic than the cycloplegic SE in the 16–45-year-old participants.\textsuperscript{30} In addition, the myopia would continue to progress after the age of 18 years in some subjects.\textsuperscript{29, 31} As a result, the non-cycloplegic parental SE in the present study may also underestimate the generational myopic shift. Hence, these various methodological biases may contribute to the underestimation of the generational myopic shift in

---

Figure 2  Refractive error difference (RED) from parents to children as a function of children’s combined age (open circle) and its binomial fitting values (filled circle). The binomial fitting function was RED = −0.025a^2+1.01a−8.00 (’a’ stands for the children’s age). RED was defined as parental spherical equivalent (SE) minus children’s SE, plotted is the median and 25th and 75th percentile. Children’s combined age was defined as the average of every two adjacent ages.

Figure 3  Proportion of children with higher myopic spherical equivalent than their parents as a function of children’s combined age (open circle) and its binomial fitting values (filled circle). The binomial fitting function was percentage = −0.78a^2+26.39a−143.42, respectively (’a’ stands for the children’s age). Children’s combined age was defined as the average of every two adjacent ages.
the present study and thus may represent a conservative estimate of the generational myopic shift.

For the current study, the students mainly in the low grades in the elite primary or secondary schools were arbitrarily selected for participation in the BMPS. This may have led to undersampling in some age groups, as well as a bias towards higher socio-economic status and/or educational attainment. Hence, further investigations with larger sample sizes on RED are warranted. Parallel investigations in rural children and different ethnic groups would be equally interesting. It is also noteworthy that our study had some information bias, because 23.5% of the parental refractive error was obtained through self-reporting. However, analysis for RED with both parents’ refractive error tested in the clinical centre (n=224) demonstrated a good consistency. The RED was −2.53 D, −1.97 D, 0.42 D, 0.38 D, 1.84 D and 1.50 D compared with −1.88 D, −1.63 D, 0.42 D, 0.44 D, 1.84 D and 1.53 D for all the 395 families of children in each combined age group. It will be optimal to include those aged 18–25 years as well, which would help to predict the generational myopic shift in this part of China.

In summary, this report provides information on the RED between parents and their children in urban China. At the age of 11 years, the SE of children would reach the average SE of their parents, and the estimated myopic shift at 18 years of age would be nearly 2.0 D. This generational myopic shift provides an evidence of a cohort effect on the increasing prevalence of myopia over generations of young adults, presumably due to environmental factors such as near-work.

Contributors YBL contributed to study design; ZL and YBL conducted the study; ZL, TYG and SSR collected the data; VI, AV and YBL were involved in management; ZL, VI and TYG contributed to the analysis of data; ZL, VI and YBL were in charge of the interpretation of the data and preparation of the manuscript; AV, YBL and NW were responsible for the provision of materials and resources, review and approval of the manuscript.

Competing interests None.

Funding This study was supported by Beijing Science and Technology Novel Star Program (2009B44).

Patient consent Obtained.

Ethics approval The ethics committee of Beijing Tongren Hospital.

Provenance and peer review Not commissioned; externally peer reviewed.

Open Access This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC-BY-NC 3.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/3.0/

REFERENCES
Generational difference of refractive error in the baseline study of the Beijing Myopia Progression Study

Yuan Bo Liang, Zhong Lin, Balamurali Vasudevan, Vishal Jhanji, Alvin Young, Tie Ying Gao, Shi Song Rong, Ning Li Wang and Kenneth J Ciuffreda

Br J Ophthalmol 2013 97: 765-769 originally published online April 16, 2013
doi: 10.1136/bjophthalmol-2012-302468

Updated information and services can be found at:
http://bjo.bmj.com/content/97/6/765

These include:

References
This article cites 31 articles, 10 of which you can access for free at:
http://bjo.bmj.com/content/97/6/765#BIBL

Open Access
This is an open-access article distributed under the terms of the Creative Commons Attribution Non-commercial License, which permits use, distribution, and reproduction in any medium, provided the original work is properly cited, the use is noncommercial and is otherwise in compliance with the license. See: http://creativecommons.org/licenses/by-nc/3.0/ and http://creativecommons.org/licenses/by-nc/3.0/legalcode

Email alerting service
Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

Topic Collections
Articles on similar topics can be found in the following collections

Open access (255)

Notes

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/