Population Density and Refractive Error among Chinese Children

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PURPOSE. China is urbanizing rapidly, and the prevalence of myopia is high. This study was conducted to identify the reasons for observed differences in the prevalence of myopia among urban versus rural Chinese children.

METHODS. All children with uncorrected acuity of 6/12 or worse and a 50% random sample of children with vision better than 6/12 at all secondary schools in mixed rural–urban Liangying Township, Guangdong, underwent cycloplegic refraction, and provided data on age, gender, parental education, weekly near work and time outdoors, and urban development level of respondents’ neighborhoods (12-item questionnaire). Population density of 32 villages and urban zones in Liangying was calculated from census figures (mean population density, 217 persons/km²; range, 94–957; mean for Guangdong, 486).

RESULTS. Among 5844 eligible children, 4612 (78.9%) had parental consent and completed examinations; 2957 were refracted per protocol, and 2480 (83.9%) of these had questionnaire data. Those with completed examinations were more likely to be girls (P < 0.001), and questionnaire respondents were more myopic (P = 0.02), but otherwise did not differ significantly from nonrespondents. In multivariate models, older age (P < 0.001), more near work (P = 0.02), and higher population density (P = 0.003), but not development index, parental education, or time outdoors were significantly associated with more myopic refractive error.

CONCLUSIONS. Higher population density appears to be associated with myopia risk, independent of academic activity, time spent outdoors, familial educational level, or economic development, factors that have been thought to explain higher myopia prevalence among urban children. Mechanisms for this apparent association should be sought. (Invest Ophthalmol Vis Sci. 2010;51:4969–4976) DOI: 10.1167/iovs.10-5424

The number of persons with visual acuity ≤6/18 due to refractive error lies between 82 and 184 million, comprising a third to a half of all those with vision disability in the world today.1,2 Given the magnitude of the problem, there has been much interest in understanding the risk factors for refractive error, particularly those that might be amenable to intervention. A consistent observation across studies has been that myopia prevalence is higher among children living in urban areas than in those in rural areas.3–9 Understanding of this phenomenon has been complicated by the fact that urban and rural environments differ in a variety of ways, several of which may be associated causally with myopia risk. Such factors may include differences in educational attainment,10 near work (e.g., visual activity with a high accommodative demand),10–13 and outdoor activity.14 Recently, it has been suggested that a fundamental spatial aspect of the urban environment itself—namely, population density—is independently associated with the risk of myopia.15

There is evidence from studies in urban16,17 and rural1,6 China, Singapore,16 Taiwan,17 Hong Kong,18 and Australia19 that children of Chinese descent often have a high prevalence of myopia. There is further evidence that this already high prevalence of myopia among Chinese children may be rising.17 Urbanization is also increasing rapidly in China, as a consequence both of large-scale migration from the countryside to the city and of rapid economic development throughout much of the country. Data from the United Nations indicate that the proportion of China’s population dwelling in urban environments rose from 13% in 1950 to 40% in 2005, with a further increase to 60% projected by 2030.20 It is unlikely that the simple dichotomy of rural and urban adequately encompasses the complex spectrum of social environments between China’s largest cities and its least developed rural areas. Researchers have proposed instruments to describe the spectrum of rural and urban environments in China21 and have developed a Chinese Urbanization Index to measure the potential impact of this complex variable on a variety of diseases, including obesity and hypertension.22

We collected refractive information on a random sample of all junior and senior high school students in a mixed rural–urban area in southern China, while obtaining census-based data on population density and administering questionnaires on parental education, near work, time spent outdoors, and the development level of the respondents’ neighborhood (adapted from the Chinese Urbanization Index).22 Our goal was to determine whether population density is associated with refractive outcomes after adjustment for a variety of factors that potentially explain urban–rural differences in myopia prevalence among children.

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These authors contributed equally to the work presented here and should therefore be regarded as equivalent authors.

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METHODS

The See Well to Learn Well project is an ongoing randomized trial of interventions to promote spectacle wear among 10,000 secondary school children in three towns in the rural Chaoshan region of southern China. Participants are selected at random from year 1 and 2 classes at all junior and senior high schools in the area (age range generally, 12–16 years). Written informed consent is obtained from at least one parent of all participants. The protocol was approved in full by Ethics Committees at the Chinese University of Hong Kong and the Joint Shantou International Eye Center (Guangdong Province, China), and the tenets of the Declaration of Helsinki were adhered to throughout. The protocol has been described elsewhere in detail in reports on data collected from a different township in the study sample frame\(^{23,24}\) and is reviewed here briefly.

Subjects

All year 1 and 2 classes (average size, ~60 children) in the five junior high schools and one senior high school of Liangying Township, Guangdong Province, were enumerated, and classes were selected at random until a total of 600 children (usually, 8–10 classes) had been identified in the sampling frame. Our pilot testing in the area had demonstrated that participation rates were on the order of 80% to 85%, meaning that 600 children in the sampling frame would be sufficient to guarantee our target of 500 children examined at each school.

Measurement of Visual Acuity and Refraction

Visual acuity with and without habitual refraction, if available, was measured by trained study personnel in well-lit areas of the school during daylight hours, at a distance of 5 m, separately for each eye of each child. Children who did not have their spectacles at school were asked to bring them for vision assessment on a separate day. Illuminated Snellen tumbling-E vision charts (Shantou City Medical Equipment, Ltd., Shantou, China) were used for all testing. The nontested eye was covered by the subject with a handheld occluder, with proper occlusion and neutral head position monitored by the examiner. The
TABLE 1. Comparison According to Gender of Children Who Completed a Population Questionnaire and Those Who Did Not, in a Sample of 4612 Rural Chinese Secondary School Children

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>All Participants (n = 4612)</th>
<th>Those Completing Refraction (n = 2957)</th>
<th>Those Completing Questionnaire and Refraction (n = 2480)</th>
<th>Those Not Completing Questionnaire (n = 2035)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All (n = 4612)</td>
<td>Refracted (n = 2957)</td>
<td>Not Refracted (n = 1655)</td>
<td>P</td>
</tr>
<tr>
<td>Age, y†</td>
<td>13.7 (1.1)</td>
<td>13.7 (1.1)</td>
<td>13.7 (1.1)</td>
<td>0.30</td>
</tr>
<tr>
<td>Gender, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>2287 (49.6)</td>
<td>1312 (44.4)</td>
<td>975 (58.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Female</td>
<td>2325 (50.4)</td>
<td>1645 (55.6)</td>
<td>680 (41.1)</td>
<td>257 (55.9)</td>
</tr>
<tr>
<td>Parents’ highest education, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary or below</td>
<td>1170 (25.4)</td>
<td>782 (26.4)</td>
<td>388 (23.4)</td>
<td>0.54</td>
</tr>
<tr>
<td>Junior and high school</td>
<td>2481 (53.8)</td>
<td>1612 (54.5)</td>
<td>869 (52.5)</td>
<td>120 (25.2)</td>
</tr>
<tr>
<td>College or above</td>
<td>517 (6.8)</td>
<td>209 (7.1)</td>
<td>108 (6.5)</td>
<td>14 (2.9)</td>
</tr>
<tr>
<td>Missing data</td>
<td>644 (14.0)</td>
<td>554 (12.0)</td>
<td>290 (17.5)</td>
<td>288 (60.4)</td>
</tr>
<tr>
<td>Median uncorrected vision in the better eye‡</td>
<td>0.80 (0.63–1.00)</td>
<td>0.63 (0.50–0.80)</td>
<td>1.00 (1.00–1.25)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Myopia ≤ −2.0 D in both eyes, n (%)</td>
<td>208 (43.6)</td>
<td>1227 (49.5)</td>
<td>0.02</td>
<td>208 (43.6)</td>
</tr>
<tr>
<td>Population density (person/km²)†</td>
<td>303 (215)</td>
<td>320 (220)</td>
<td>269 (199)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Development score†</td>
<td>1.21 (0.41)</td>
<td>1.22 (0.42)</td>
<td>1.20 (0.41)</td>
<td>0.007</td>
</tr>
</tbody>
</table>

* Data for parental education, population density, and development index reflect available data from partially completed forms.
† Mean (SD).
‡ Median (interquartile range). Vision data are presented as the Snellen decimal fraction. The logarithm of the inverse of this value (logMAR) was used for statistical calculations, but the untransformed value is presented in this table for clarity.
right eye was tested first. A single optotype of each size was presented first, at 6/30. If a letter was not identified, testing began 2 lines above, with the child being asked to read all optotypes on the line sequentially. A subject had to identify correctly more than half of the letters on a given line (e.g., three of five or four of six) to be considered to have achieved that level of acuity.

All subjects with uncorrected visual acuity of 6/12 or worse in either eye and a random 50% sample of children with vision better than 6/12 in both eyes underwent cycloplegic autorefraction (model PRK-5000; Potec, Co. Ltd., Seoul, Korea). Subjective refinement was performed by an ophthalmologist in each eye, at least 30 minutes after the child received 1 drop of cyclopentolate 1% in both eyes every 5 minutes, for a total of 2 drops in each eye (Fig. 1).

**Questionnaires and Population Density Data**

All participants were given a self-administered questionnaire before being told the results of the vision assessment. Respondents were asked to describe the highest educational level of each parent, with the level reached by the most-educated parent being used in the analyses. Also, as previously described,25 subjects reported the number of hours spent during the previous week in each of the following four activities: schoolwork (at home and in school), personal reading, watching television, video games and computer use, and outdoor activities of all kinds. Subjects were also asked to indicate their preferred working distance for each task except outdoor activities. These working distances were used to calculate estimated accommodative effort in diopters (the inverse of the working distance in meters) for each task, which were in turn multiplied by the indicated number of hours spent, to give the weekly number of task-specific dioptric hours.

In addition, children were administered a 12-item questionnaire adapted from the Community Survey of the University of North Carolina’s Chinese Health and Nutrition Survey.21,22 The questions are designed to assess the level of development in a community and include items assessing the characteristics and availability of roads (dirt, gravel, or paved), public transportation, and telephone, electrical, postal, newspaper, and internet services. Four items adapted from the Sydney Myopia Study15,26 were also included—specifically, those on the respondent’s housing type and the visibility from the respondent’s home of other dwellings, commercial structures, and the horizon. A score ranging from 0 (least developed) to 30 (most developed) was calculated. A sub-score was constructed from these items by awarding more points for responses indicative of a more urban, or developed, environment, as adapted from the China Urbanization Index.22 All questions were weighted equally, with the final development score being divided by the number of responses for analysis, to avoid any effects of nonresponse to one or more items. This score ranged from 0 to 2.5.

Finally, respondents were instructed to select the village or urban zone in which they had spent most of their time in the past 10 years, from a list of 32 such areas present in Liangying Township. Data on population (2004 census) and total area of each of 29 villages and three urban zones in Liangying were obtained from the county-level Ministry of Education, and these were used to calculate population density (persons/km²) (mean, 217; range, 94–957; mean for Guangdong, 27486; mean for China, 27139; and mean for Guangzhou, 28 capital of Guangdong, 1351). Liangying is a mixed urban–rural area with a population density of 2480 children within Shantou, a city of 4.97 million persons at the end of 2006, in eastern Guangdong Province.

**Statistical Methods**

Demographic and clinical differences between participants and nonparticipants, male and female participants, and participants with and without −2.0 D or more of spherical equivalent myopia in both eyes were analyzed with χ²-tests (continuous data) and Fisher’s exact tests (discrete data), as appropriate. We created multivariate linear regression models with spherical equivalent refractive error in the better-seeing eye as the outcome. The Shapiro-Wilk test was used to verify the assumption of normality for the principal explanatory variables, and plots of residuals versus predicted values were prepared that verified the assumption of linear relationships. Potential predictors in the model were selected a priori from among factors that have been reported to be linked to myopia, including age, gender, parental education, near work (self-reported total weekly dioptric hours), outdoor activity (total hours per week outdoors), and population density. In addition, the development score based on the China Urbanization Index was included in the model, to adjust for level of urbanization as a possible risk factor for myopia.

An alternative logistic regression model was also used to explore the identical predictors with the outcome of having −2.0 D myopia and including all children (unrefracted children with normal vision in both eyes were presumed not to be myopic at the −2.0 D level; statistical analyses performed with SPSS, ver. 16; SPSS Inc., Chicago, IL).

**RESULTS**

Among 5844 eligible children, vision was examined in 4612 (78.9%), whereas 605 (10.4%) could not be examined or had no parental consent and 627 (10.7%) were absent from school (Fig. 1). Children participating in the study were older (13.7 ± 1.06 vs. 13.6 ± 0.93 years, P = 0.01) and more likely to be girls (50.4% vs. 59.2%, P < 0.001) than those who did not. Among the study participants, 1751 (38.0%) had uncorrected vision 6/12 or worse in either eye, of whom 1737 (99.2%) underwent refraction per protocol, and 2861 (62.0%) had vision better than 6/12 in both eyes, among whom 1217 (42.5%) were refracted as part of a random sample (Fig. 1). Thus, refraction data were available on 2957 subjects, who were more likely to be girls (P < 0.001) than were the children not selected for refraction (Table 1). Among the refracted children, 2480 (83.5%) provided questionnaire data to assess parental education, near work, outdoor activity, and development level and population density of their village or urban zone within Liangying Township (Fig. 1). These subjects provide the basis for most of the remaining analyses.

Participants with refractive and questionnaire data had a mean age of 13.8 ± 1.1 years, 56.0% (n = 1388) were girls, and 49.5% had spherical equivalent refractive error ≤ −2.0 D in both eyes, significantly higher than for nonparticipants (43.6%, P = 0.02). Age, gender, and uncorrected vision in the better-
seeing eye did not differ between the questionnaire respondents and nonrespondents (Table 1).

Figures 2 and 3 depict the association between spherical equivalent refractive error in the better seeing eye and the development score and population density, respectively. The slopes for each differ significantly from 0 (development score, \(P < 0.005\); population density, \(P < 0.001\)). The mean population density of villages and urban zones in which children with myopia \(\leq -2.0\) D in both eyes reported living was significantly higher than that for children with refractive error \(> -2.0\) D in either eye (399 ± 221 persons/km² vs. 301 ± 217 persons/km², \(P < 0.001\)), although the mean development score did not differ significantly between the two groups (\(P = 0.15\); Table 2).

The mean total weekly hours spent by all children on near work activities was 38.3 hours, compared with 5.6 hours spent weekly on outdoor activity (Table 3). Children with myopia \(\leq -2.0\) D in both eyes reported more diopter hours of near work in homework (48.5 ± 30.3 vs. 45.0 ± 29.5, \(P = 0.005\)) and other reading (27.4 ± 27.5 vs. 23.7 ± 23.0, \(P < 0.001\)) than did children without such myopia, but self-reported outdoor activity did not differ between these two groups (\(P = 0.73\); Table 3).

Table 4 depicts the correlation matrix for our principal explanatory variables. Population density and development score showed a modest positive correlation, as did population density and population density of self-reported village or urban zone of residence of 2480 children (slope is different from zero, \(P = 0.001\)).

![Figure 3](https://iovs.arvojournals.org/)

**Figure 3.** Spherical equivalent refractive error in the better-seeing eye versus population density of self-reported village or urban zone of residence of 2480 children (slope is different from zero, \(P < 0.001\)).
density and diopter hours. In a linear regression model of the spherical equivalent refractive error in the better-seeing eye, which included only variables statistically significant at the 0.05 level in the univariate analysis, older age ($P < 0.001$), total weekly diopter hours of self-reported near work ($P = 0.02$), and higher population density ($P = 0.003$) were independently associated with more myopic refractive error. Gender, parental education, self-reported outdoor activity, and development score were not significantly associated with refractive outcome (Table 5). A similar model that included the school attended by the children (modeled using dummy variables) gave identical results (data not shown). In an alternative logistic regression model, including the same explanatory factors and with the outcome of having spherical equivalent refractive error $\leq -2.0$ D in both eyes, the identical factors were significantly associated with myopia: older age ($P < 0.001$), near work ($P = 0.001$), and population density ($P < 0.001$), although being of the female gender ($P = 0.002$) was also significantly associated in this model. The latter model (full model data not shown) included all children participating in the study with complete questionnaire data and treated children with normal vision in both eyes and without refraction data as nonmyopic. No children with myopia $\leq -2.0$ D bilaterally were identified among the 1217 children with normal vision refracted at random.

**DISCUSSION**

Urban residence in China may be associated with increased prevalence of health conditions, including obesity$^{22}$ and hypertension$^{22}$ among adults and myopia$^{5-7}$ and obesity$^{8}$ among children. The widely reported excess burden of myopic refractive error among urban children in various settings has often been attributed to enhanced exposure to several factors that may increase myopia risk, including higher educational attainment$^{10-13}$, increased near work due to school demands$^{10-13}$, and lack of outdoor activity$^{14}$ in an urban environment. Our results suggest that greater population density is an independent risk factor for myopia, even when adjustment is made for these factors. This relatively novel result is consistent with findings recently reported by investigators for similarly aged children in Australia,$^{15}$ including those of East Asian ancestry. Although urban residence has been linked with greater myopia prevalence in ethnically Chinese populations,$^{3-7}$ ours is the first report of which we are aware that has identified population density as an independent risk factor for myopia in China, a country with the second largest population of children in the world and among the greatest burdens of pediatric refractive error. Furthermore, previous reports of urban-rural differences in myopia prevalence in Chinese populations have not used China-specific indices of development to adjust for possible economic differences between the environments under comparison.

The impact of population density on myopia in this cohort appears to have been modest, with a difference of 1.0 to 1.5 D between the mean spherical equivalent of children dwelling in the most and least densely populated areas (Fig. 3, Table 5). It is not clear that this effect would be sufficient to explain much of the apparent secular increase in myopia prevalence that has occurred recently in ethnic Chinese populations. However, due to rapid changes in population density and the phenomenon of migration, both increasingly common in China, the population density recorded most recently at the current place of residence for some study participants may not provide an accurate assessment of lifetime exposure. This limitation may tend to diminish the strength of the observed association between population density and refractive error. Further studies taking account of such factors, perhaps prospectively, may be needed for accurate assessment of the magnitude of any association between population density and refractive error.

The biological mechanism for a putative independent effect of greater population density on myopia risk remains unclear. Myopia was associated with living in smaller, more confined housing in an Australian study of the effect of urban environments on refractive error.$^{15}$ This finding raises the possibility that the more closely confined environments associated with greater population density are somehow increasing the baseline accommodative burden among children as a pathway mediating increased myopia risk. However, these associations are potentially confounded by socioeconomic status: In Singapore, adult myopia was associated with larger dwelling size.$^{29}$

**Table 4.** Correlation Matrix for Principal Explanatory Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Age</th>
<th>Development Score</th>
<th>Diopter Hours</th>
<th>Population Density</th>
<th>Outdoor Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>1.000</td>
<td>0.038</td>
<td>0.073</td>
<td>0.074</td>
<td>0.065</td>
</tr>
<tr>
<td>Development score</td>
<td>0.038</td>
<td>1.000</td>
<td>−0.047</td>
<td>0.082</td>
<td>0.155</td>
</tr>
<tr>
<td>Diopter hours</td>
<td>0.073</td>
<td>−0.047</td>
<td>1.000</td>
<td>0.031</td>
<td>0.184</td>
</tr>
<tr>
<td>Population density</td>
<td>0.074</td>
<td>0.082</td>
<td>0.031</td>
<td>1.000</td>
<td>0.030</td>
</tr>
<tr>
<td>Outdoor activity</td>
<td>0.065</td>
<td>0.155</td>
<td>0.184</td>
<td>0.030</td>
<td>1.000</td>
</tr>
</tbody>
</table>

**Table 5.** Association between Spherical Equivalent Refractive Error in the Better-Seeing Eye and Potential Predictors of Refractive Error among 2480 Chinese Secondary School Children Living in a Mixed Rural-Urban Area

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Univariate Analysis $P$</th>
<th>Beta (Mean and 95% CI)</th>
<th>$P$</th>
<th>Beta (Mean and 95% CI)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>0.001</td>
<td>−0.159 (−0.241 to −0.077)</td>
<td>0.001</td>
<td>−0.153 (−0.234 to −0.072)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gender, female</td>
<td>0.09</td>
<td>−0.165 (−0.343 to 0.018)</td>
<td>0.08</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Greater parental education</td>
<td>0.14</td>
<td>−0.065 (−0.213 to 0.83)</td>
<td>0.39</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total near work (diopter hours/week)</td>
<td>0.002</td>
<td>−0.002 (−0.003 to 0.000)</td>
<td>0.04</td>
<td>−0.002 (−0.003 to 0.000)</td>
<td>0.02</td>
</tr>
<tr>
<td>Outdoor activities (hours/week)</td>
<td>0.49</td>
<td>−0.004 (−0.019 to 0.011)</td>
<td>0.61</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Population density (persons/km2)</td>
<td>&lt;0.001</td>
<td>−0.567 (−0.955 to −0.018)</td>
<td>0.004</td>
<td>−0.596 (−0.983 to −0.209)</td>
<td>0.003</td>
</tr>
<tr>
<td>Development score</td>
<td>0.09</td>
<td>−0.126 (−0.335 to 0.84)</td>
<td>0.56</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Bold data denote significant results.
In the present study, we found no association between myopia and a development index that included several variables specifically assessing dwelling size and the closeness of other structures. Moreover, our model adjusted for accommodative demand associated with reading and various other activities that would be expected to be substantially greater than that induced by living in a more closely confined dwelling. Environmental differences between urban and rural settings in China are no doubt complex. Urban dwelling in China has been associated with excess exposure to pollution, noise, disturbed sleep, and adolescent stress, all of which have been linked to increased risk of various health conditions. Further work is needed to determine whether any of these factors are associated with myopia risk. Such research may lead to a better understanding of the pathogenesis of myopia.

Our strategy of refracting only children with uncorrected vision of 6/12 or worse in at least one eye, together with a random 50% sample (actually 42.5% were examined) of those with vision better than 6/12 in both eyes, resulted, as expected, in our including children who were significantly more myopic than the school cohort at large (Table 1). As children were chosen at random for refraction, the selection process would not be expected to produce confounding of our results. This strategy yielded refraction data for nearly two thirds (2957/4612 = 64.1%) of children in the cohort. That an analytic strategy including all 4612 children produced essentially the same results with regard to population density, near work, outdoor activity, and the development index makes it less likely that our main results are unduly affected by the selection protocol for refraction.

Our finding of an association between older age and increasing risk of myopia has been reported among children of Chinese4–7 and European33 descent and may be an indication of exposure to more years of schooling. Reports on the association of myopia risk with near work11–15,29 and outdoor activity25,33 among ethnically Chinese children have not been entirely consistent. In our own investigation of myopia in a similarly aged population in the same region of China, we did not detect a significant association with either of these factors33; statistical power in the current investigation to detect such associations is enhanced by the much larger sample size. Given the rather modest amount of time reported outdoors on a weekly basis by children in this cohort, we cannot exclude the possibility that the range of exposure was insufficient to clearly elucidate an underlying relationship. Randomized controlled trials of outdoor activity among Chinese school-children are currently under way to resolve this issue.

Results of and inferences drawn from the present study must be viewed with a clear understanding of its limitations. This cohort was drawn from all secondary schools in Liangying Township, and school enrollment in similar regions of Guangdong exceeds 90%.34 However, the study design did not call for population-based enrollment and there appeared to be minor differences in age and more significant ones in the gender of the participants and nonparticipants, in addition to the expected higher prevalence of refractive error, as discussed earlier. Thus, generalization of these results to the population of this region and beyond must be made with caution.

The data we collected on near work were dependent entirely on self-report, and were not supplemented by diaries or other surveillance mechanisms, raising the possibility of recall bias. Moreover, the directionality of any cause-and-effect relationship between near work and myopic refractive error cannot be directly inferred from a cross-sectional study such as the present one. Thus, we cannot exclude the possibility that the observed association was partly due to a closer reading distance resulting from more myopic refractive error, rather than to more near work being a cause of myopia.

With regard to outdoor activity, children were asked only about activity over the most recent week, which may not have been representative of behavior throughout the year. This limited time frame was used to maximize the accuracy of recall, and the failure to fully reflect typical behavior may be minimized by the fact that the schools were surveyed at different times throughout the school year. Still, the possibility of our having collected unrepresentative data, resulting in an underestimation of the impact of outdoor activity on myopia, cannot be excluded. The observed positive correlation between dioptric hours of near work and outdoor activity (Table 4) has been reported in studies in both Sydney4 and Orinda.35 Although population density figures were available for relatively small administrative divisions (average size, ~2000 persons), these average statistics did not necessarily reflect exactly the experience of any individual child within a given village or urban zone. Such imprecision would generally tend to decrease rather than increase the observed association between population density and refractive error. That population density and development score are somewhat correlated (Table 4) raises the possibility of co-linearity in our model; that population density was significant in both the univariate and multivariate analyses and development score was significant in neither makes it less likely that such co-linearity influenced our results excessively. The correlation between these two factors was lower than might have been expected. Given the Chinese government's stated goal of attempting to redress urban–rural imbalances, it may be that targeted government investment in rural areas has led to a greater mismatch between development indicators and population density than there might be otherwise. Finally, there may be other important factors associated with both the urban experience and myopic risk that we were unable to evaluate (such as household income, which proved to be impractical to ascertain in this context). These could have confounded the associations we sought to assess. We initially thought that differences in schools attended by the children might be such a confounder, but that seems less likely in view of the lack of effect of school in regression models of refractive outcome.

Despite these limitations, this investigation provides, for the first time, evidence of a potentially novel risk factor for myopia highly relevant to current social trends in China, a country with arguably the world's greatest burden of pediatric refractive error. Further research is needed to better understand the mechanisms underlying the apparent association between population density and myopia risk in this and other populations.

References


