Myopia and the Urban Environment: Findings in a Sample of 12-Year-Old Australian School Children

Jenny M. Ip,1 Kathryn A. Rose,2 Ian G. Morgan,3 George Burlutsky,1 and Paul Mitchell1

PURPOSE. To examine associations between myopia and measures of urbanization in a population-based sample of 12-year-old Australian children.

METHODS. Questionnaire data on sociodemographic and environmental factors including ethnicity, parental education, and time spent in near work and outdoor activities were collected from 2367 children (75.0% response) and their parents. Population density data for the Sydney area were used to construct five urban regions. Myopia was defined as spherical equivalent refraction ≤ −0.50 D.

RESULTS. Myopia prevalence was lowest in the outer suburban region (6.9%) and highest in the inner city region (17.8%), with mean refraction tending toward greater myopia by region (outer suburban to inner city), after adjustment for age, sex, ethnicity, near work, outdoor activity, and parental myopia. Multivariate-adjusted analyses confirmed greater odds for myopia in regions of higher population density (P<sub>retool</sub> = 0.0001). Myopia was significantly more prevalent among children living in apartment residences than other housing types (χ² < 0.0001), after adjustment for ethnicity, near work, and outdoor activity. Housing density (measured as the number of houses visible from a front door) was not significantly associated with myopia (χ² = 0.1). For both European Caucasian and East Asian children, myopia was most prevalent in the inner city region (8.1% and 55.1%, for European Caucasian and East Asian, respectively).

CONCLUSIONS. The higher myopia prevalence in inner city/urban areas compared with outer suburban areas for this large childhood sample suggest that even moderate environmental differences within a predominantly urban setting may be associated with increased odds of myopia. These findings are consistent with previous reports of rural-urban differences in childhood myopia. (Invest Ophthalmol Vis Sci. 2008;49:3858–3863) DOI:10.1167/iovs.07-1451

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Parents also completed a 173-item questionnaire that collected detailed sociodemographic data, such as ethnicity, the level of education completed, and the occupation of both parents. To ascertain whether they had myopia, parents were asked whether they needed to use spectacles or contact lenses, the age at first use, and the reason for using spectacles (for distance viewing only, for near work only, or whether spectacles were used for both distance viewing and near work). Spectacle prescriptions were also obtained from parents or their prescribers, where possible. Spectacle prescriptions confirming questionnaire data were available for 23% and 26%, respectively, of the mothers and fathers.

For the purposes of this study, the greater Sydney region was divided into 14 areas, based on spatial units (statistical subdivisions), defined by the Australian Bureau of Statistics (ABS) to delineate relatively homogeneous social and economic regions. The 14 areas of greater Sydney were then grouped by population density (ABS data collected in 2004) into five regions: <100 persons/km² (region 1, outer suburban); 100 to 999 persons/km² (region 2); 1000 to 1999 persons/km² (region 3); 2000 to 2999 persons/km² (region 4); and ≥3000 persons/km² (region 5, inner city). Participating children were allocated to one of the five regions, according to their residential postcode. ABS data for 2001, 2003, and 2004 showed that on average, inhabitants of more densely populated regions reported higher levels of educational attainment and greater income, compared with those living in regions with lower population density (Table 1).

### Examination

After amethocaine was instilled, cycloplegia was induced with cyclopentolate 1% (2 drops). In a few children, tropicamide 1% (1 drop) and phenylephrine 2.5% (1 drop) were also used to obtain adequate miosis (minimum pupil diameter 6 millimeters). Autorefration was performed at approximately 25 to 30 minutes after the last drop (RK-F1 autorefractor; Canon, Tokyo, Japan). Cycloplegic autorefration was used, as this method of examination has been shown to provide more reliable measurements in young children than cycloplegic retinoscopy or noncycloplegic autorefration.21

### Definitions

Myopia was defined as spherical equivalent refraction (sphere + 1⁄2 cylinder) −0.50 D or less. Parental ethnicity was classified on the basis of self-identification, and in the child if both parents shared that ethnic origin. The ethnic categories (European Caucasian, East Asian, South Asian, Middle Eastern, Pacific Islander, Indigenous Australian, African, and South American) were largely consistent with the Australian Standard Classification of Cultural and Ethnic groups (available at http://www.abs.gov.au, document 1249.0). Children with parents of different ethnicity were classified as having mixed ethnicity. European Caucasian ethnicity comprised 60.0% and East Asian ethnicity 15.0% of the whole sample.

### Data Analysis

Data were analyzed using commercial software (SAS ver. 9.1.3; SAS Institute, Cary, NC). Mixed models and generalized estimating equations were used to examine associations and subgroup differences, adjusting for the effects of cluster-sampling. Analyses for myopia and spherical equivalent refraction were performed for the whole sample and separately for the two predominant ethnic subgroups (European Caucasian and East Asian). T-tests and $ \chi^2 $ tests were used when cluster effects were not significant. All confidence intervals (CIs) are 95%.

### Results

#### Sample Characteristics

Overall, 2367 (75.0%) children attending year 7 in the selected schools had parental permission to participate. Of these, 14 were not examined, because they were absent during the school visit. The mean age of participants was 12.7 years (range, 11.1–14.4 years). Ethnic origins of the participating children were predominantly European Caucasian (64.5%) and East Asian (15.0%). Nonparticipants were similar to participants by sex (51.6% and 50.0% were boys, respectively) and ethnicity (67.8% of nonparticipants were European Caucasian). Overall, 82.8% of nonparticipants and 83.8% of participants attended public schools.

Of the 2355 children examined, only 44 lived outside of the greater Sydney area, boarded at schools, or could not be located by postcode, and were therefore excluded from the analyses. Of the remaining 2309 children with available data, 322 (14.0%) lived in region 1, 703 (30.5%) in region 2, 710 (30.7%) in region 3, 304 (13.2%) in region 4, and 270 (11.7%) in region 5. The majority (94.0%) of children had lived at their current address for 6 months or longer. On average, the samples of children living in more densely populated regions were very slightly but significantly older ($ P < 0.0001 $) and included greater proportions of girls ($ \chi^2 < 0.0001 $) and children of East Asian ethnicity ($ \chi^2 < 0.0001 $; Table 2). In more densely populated regions, higher levels of parental education and parental myopia were also noted (both $ \chi^2 < 0.0001 $). The time that children spent in near-work activities was similar across the five regions ($ P = 0.1 $), but significantly less time in outdoor activity was reported by children living in more densely populated areas ($ P = 0.0006 $).

### Table 1. Select Socioeconomic Factors in Sydney Regions (Statistical Range) Stratified by Population Density

<table>
<thead>
<tr>
<th>Region 1* (Outer Suburban)</th>
<th>Region 2</th>
<th>Region 3</th>
<th>Region 4</th>
<th>Region 5 (Inner City)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population density (persons/km²)</td>
<td>49.1–78.5</td>
<td>446.6–921.0</td>
<td>1,098.3–1,160.7</td>
<td>2,282.0–2,812.4</td>
</tr>
<tr>
<td>Socioeconomic factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completed university degree (%)</td>
<td>5.9–7.7</td>
<td>6.0–18.6</td>
<td>7.8–10.8</td>
<td>7.7–10.3</td>
</tr>
<tr>
<td>Unemployed (%)</td>
<td>4.6–8.0</td>
<td>2.6–6.2</td>
<td>3.5–7.2</td>
<td>3.9–7.6</td>
</tr>
<tr>
<td>Ethnicity (%)†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>European</td>
<td>78.0–87.4</td>
<td>48.6–82.6</td>
<td>62.9–73.7</td>
<td>47.3–49.1</td>
</tr>
<tr>
<td>East Asian</td>
<td>1.3–3.1</td>
<td>2.5–17.5</td>
<td>8.5–9.1</td>
<td>12.5–13.9</td>
</tr>
<tr>
<td>Middle Eastern or North African</td>
<td>0.7–1.2</td>
<td>0.3–9.9</td>
<td>1.9–2.5</td>
<td>10.5–12.5</td>
</tr>
<tr>
<td>Speaks language other than English at home (%)</td>
<td>9.3–14.7</td>
<td>11.4–55.3</td>
<td>26.1–28.5</td>
<td>43.9–52.7</td>
</tr>
</tbody>
</table>

Population densities were determined from census data of 2001, 2003, and 2004. Region 1 denotes areas of lowest population density (<100 persons/km²), and region 5 denotes areas of highest population density (≥3000 persons/km²).

* Regions are categorized based on the population density data obtained in the 2004 census, provided by the Australian Bureau of Statistics.

† Based on self-identification.
Childhood Myopia and Urbanization

For this cross-sectional sample of 12-year-old children, the prevalence of childhood myopia was lowest (6.9%) in the outer suburban region and highest (17.8%) in the inner city region. The mean childhood spherical equivalent refraction by region (outer suburban to inner city) followed a trend toward greater myopia, after adjustment for age, sex, near work, outdoor activity, and parental myopia (Table 3).

Stratifying by ethnicity showed a similar trend of less hyperopic–more myopic refraction from the outer suburban region to the inner city region in both European Caucasian and East Asian ethnic groups (Table 3). Across all regions, children of European Caucasian ethnicity were consistently more hyperopic in refraction, with a lower prevalence of myopia, than children of East Asian ethnicity.

Type of Housing and Housing Density

Myopia was significantly more frequent in children who lived in smaller, confined housing types such as terrace houses (21.4%) and apartments (26.3%) than those living in stand-alone or separate houses (11.3%, \( \chi^2 < 0.0001 \); Table 4). The odds for childhood myopia associated with living in a terrace house was 2.0 (95% CI, 1.4–2.9) and for living in an apartment was 2.2 (95% CI, 1.6–3.1), after adjustment for region.

### Table 2. Characteristics of Participating 12-Year-Old Children, Stratified by the Population Density of the Area of Residence

<table>
<thead>
<tr>
<th>Region 1 (Outer Suburban)</th>
<th>Region 2</th>
<th>Region 3</th>
<th>Region 4</th>
<th>Region 5 (Inner City)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n = 322 )</td>
<td>( n = 703 )</td>
<td>( n = 710 )</td>
<td>( n = 304 )</td>
<td>( n = 270 )</td>
</tr>
<tr>
<td>Mean age (SD)*</td>
<td>12.7 (0.4)</td>
<td>12.6 (0.4)</td>
<td>12.6 (0.4)</td>
<td>12.8 (0.4)</td>
</tr>
<tr>
<td>Sex (n, %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls†</td>
<td>152 (47.2)</td>
<td>327 (46.5)</td>
<td>326 (45.9)</td>
<td>184 (60.5)</td>
</tr>
<tr>
<td>Boys</td>
<td>170 (52.8)</td>
<td>376 (53.5)</td>
<td>384 (54.1)</td>
<td>120 (39.5)</td>
</tr>
<tr>
<td>Ethnicity (n, %)†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>European Caucasian</td>
<td>210 (65.2)</td>
<td>446 (63.4)</td>
<td>437 (61.6)</td>
<td>91 (29.9)</td>
</tr>
<tr>
<td>East Asian</td>
<td>24 (7.5)</td>
<td>121 (17.2)</td>
<td>85 (12.0)</td>
<td>70 (23.0)</td>
</tr>
<tr>
<td>Highest parental education (n, %)†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High school</td>
<td>86 (31.4)</td>
<td>104 (16.6)</td>
<td>180 (28.6)</td>
<td>70 (28.3)</td>
</tr>
<tr>
<td>TAFE</td>
<td>116 (42.3)</td>
<td>249 (39.8)</td>
<td>259 (41.1)</td>
<td>79 (32.0)</td>
</tr>
<tr>
<td>University</td>
<td>72 (26.3)</td>
<td>273 (43.6)</td>
<td>191 (30.3)</td>
<td>98 (39.7)</td>
</tr>
</tbody>
</table>

Parental myopia (n, %)†

No parents with myopia 166 (67.5) 320 (58.1) 378 (68.5) 126 (63.6) 116 (52.3)
Two parents with myopia 9 (3.7) 49 (8.9) 19 (3.4) 18 (9.1) 31 (14.0)

Mean time spent doing near work (SD) 26.8 (14.6) 26.9 (15.1) 27.6 (15.1) 29.4 (14.2) 27.5 (11.0)

Mean time spent in outdoor activity (SD)* 13.3 (8.6) 11.6 (7.1) 12.8 (7.6) 11.2 (7.6) 11.9 (7.0)

* \( P < 0.0001 \) for differences between the five regions.
† \( \chi^2 < 0.0001 \) for differences between the five regions.

### Table 3. Refraction and Myopia Prevalence in 12-Year-Old Children Stratified by Region

<table>
<thead>
<tr>
<th>Region</th>
<th>Whole sample</th>
<th>European Caucasian</th>
<th>East Asian</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( n )</td>
<td>Mean Spherical Equivalent Refraction (SEM)*</td>
<td>Proportion with Myopia (95% CI)</td>
</tr>
<tr>
<td>Region 1 (outer suburban)</td>
<td>322</td>
<td>0.28 (0.10)</td>
<td>6.9 (4.1–9.6)</td>
</tr>
<tr>
<td>Region 2</td>
<td>703</td>
<td>0.24 (0.07)</td>
<td>11.7 (9.3–14.0)</td>
</tr>
<tr>
<td>Region 3</td>
<td>710</td>
<td>0.18 (0.07)</td>
<td>9.7 (7.5–11.9)</td>
</tr>
<tr>
<td>Region 4</td>
<td>304</td>
<td>−0.02 (0.10)</td>
<td>18.0 (13.6–22.4)</td>
</tr>
<tr>
<td>Region 5 (inner city)</td>
<td>270</td>
<td>0.12 (0.10)</td>
<td>17.8 (13.2–22.4)</td>
</tr>
</tbody>
</table>

Spherical equivalent refraction is expressed in diopters.

* Adjusted for age, sex, near work, outdoor activity, and parental myopia. Data for the whole sample also adjusted for ethnicity.
association between housing type and myopia was significant after separately adjusting for ethnicity (P = 0.02), near work (P < 0.0001), and outdoor activity (P < 0.0001). Housing density (measured as the number of homes seen from the child’s house and categorized as <5, 5–10, or >10) was not significantly associated with childhood myopia in this sample (χ² = 0.1).

Multivariate Analyses

In multivariate analyses for childhood myopia, significant variables included region (P\textsubscript{trend} = 0.0003), East Asian ethnicity (P < 0.0001), parental myopia (P < 0.0001), and outdoor activity (P = 0.005). In this sample, near work was not significantly associated with childhood myopia (P = 0.2). The children living in the inner city region had 2.2-fold greater odds for myopia than did those living in the outer suburban region (OR, 2.2; 95% CI, 1.3–3.8, Table 5), after adjustment for age, sex, ethnicity, parental myopia, parental education, and time spent in near work and outdoor activities.

For children of European Caucasian ethnicity, the odds for myopia increased with region (P\textsubscript{trend} = 0.0002), such that the inner city region had the greatest odds of having myopia (OR, 7.1; 95% CI, 2.5–19.8, compared with the outer suburban region), after adjustment for age, sex, parental myopia, parental education, and time spent in near work and outdoors (Table 5). In multivariate analyses for children of East Asian ethnicity, region was also a significant factor predicting increased odds of myopia (P\textsubscript{trend} = 0.0002). There were no statistically significant interactions between ethnicity and our measure of socioeconomic status (interaction term, ethnicity × parental education; P = 0.07).

**DISCUSSION**

The findings from this sample of predominantly 12-year-old Sydney school children suggest that the children living in regions with higher population density were significantly more likely to have myopia, after adjustment for factors such as ethnicity, parental myopia, and time spent in near work and outdoor activity. Apartment-style housing was also significantly associated with myopia after accounting for regional differences. Although several studies have reported higher myopia prevalence in rural or remote settings compared with that in urban cities, 15–18,22 this is the first study to evaluate directly the associations of moderate differences in the urban environment with myopia in samples of children also taught in the same schooling system.

**Previous Studies**

In comparing the prevalence of childhood myopia from extremes in environmental settings (rural versus urban), distinguishing effects of urbanization from the impact of other factors (e.g., education, schooling, and outdoor activity) can be difficult, so that it is not always entirely clear whether differences in myopia prevalence can be attributed to an urban environment alone. Among 12-year-old school children in China, one prevalence estimate of myopia in an urban sample was 49.7%, 15 but it ranged from 12.0% to 25.0% in semirural samples. 17 In a study of younger children in China attending school in the city or in the countryside, Saw et al. 18 reported that the proportions with myopia were 19.3% and 6.6%, respectively. In these younger children, there were also substantial differences in level of near-work activities, in the proportions with parental myopia and in the level of parental education, so that differences in myopia prevalence could not be attributed to urbanization or geographic region alone. In another study of children in Malaysia and Singapore, 23 ethnicity-specific comparisons consistently showed higher rates of myopia in Singaporean children. Although the authors proposed that environmental differences such as early schooling, population density, and apartment housing may have attributed to the differences in myopia prevalence between the two countries, specific analyses of such factors were not reported. Lithander, 22 in a survey of myopia prevalence in a sample of children from the Sultanate of Oman, found that children in rural remote areas were significantly less myopic than the rest of the sample. This finding was attributed to the high illiteracy rate and the low level of reading or writing undertaken by inhabitants in the rural areas. In a sample of rural school children in China, He et al. 16 found that school locality (urban school versus rural school) was significantly associated with myopia and was thought to be the result of various levels of near work and outdoor activity. These factors, however, were not reported.

In this study, we had a unique opportunity to assess myopia risk factors in an age-specific sample of multiethnic children living in a range of residential settings across a large metropolitan area. The significant relationships observed within an urban setting emphasize the relevance of even subtle environmental differences in childhood myopia.

The greater Sydney area in which we conducted our survey, is predominantly suburban, with a broad range of residential settings, including relatively spacious outer suburban regions plus more densely populated inner city areas. Direct comparisons of myopia's prevalence with previous studies are limited by factors such as ethnicity, levels of near work and study, and the outdoor environment. Nonetheless, the present study

**Table 4. Proportion with Myopia by Housing Type**

<table>
<thead>
<tr>
<th>Housing Type</th>
<th>Proportion with Myopia n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate house (n = 1714)</td>
<td>189 (11.3)</td>
</tr>
<tr>
<td>Terrace house (n = 126)</td>
<td>126 (21.4)</td>
</tr>
<tr>
<td>Apartment (n = 137)</td>
<td>36 (26.3)</td>
</tr>
<tr>
<td>χ²</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Other housing types such as apartment attached to house, house trailer, houseboat, or improvised home (n = 32) were excluded from the analyses.

**Table 5. Multivariate Adjusted Odds Ratio (CI) for Myopia in Children**

<table>
<thead>
<tr>
<th>Region 1 (Outer Suburban)</th>
<th>Region 2</th>
<th>Region 3</th>
<th>Region 4</th>
<th>Region 5 (Inner City)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole sample (n = 2309)*</td>
<td>1.0</td>
<td>1.2 (0.7–2.1)</td>
<td>1.8 (1.2–2.9)</td>
<td>2.0 (1.3–3.1)</td>
<td>2.2 (1.3–3.8)</td>
</tr>
<tr>
<td>European Caucasian (n = 1028)†</td>
<td>1.0</td>
<td>3.1 (1.1–8.8)</td>
<td>5.9 (2.0–17.0)</td>
<td>4.1 (1.4–12.5)</td>
<td>7.1 (2.5–19.8)</td>
</tr>
<tr>
<td>East Asian (n = 245)‡</td>
<td>1.0</td>
<td>1.3 (0.6–3.3)</td>
<td>1.0 (0.5–2.3)</td>
<td>1.6 (0.7–3.9)</td>
<td>2.0 (0.9–4.6)</td>
</tr>
</tbody>
</table>

* Adjusted for: age, sex, ethnicity, time in near work, time spent outdoors, parental myopia, and parental education.
† Adjusted for: age, sex, time in near work, time spent outdoors, and parental myopia.
shows that the myopia prevalence in the inner city area (17.8%) was substantially lower than that reported in same-age urban childhood samples from China (49.7%)\textsuperscript{15} and Malaysia (24.8%).\textsuperscript{24} In an urban childhood sample from India, the prevalence of myopia in 12-year-old children was 9.7%.\textsuperscript{25} For children of East Asian ethnicity in our sample, the prevalence of myopia in the inner city region (55.1%) was actually quite comparable to the myopia prevalence reported from East Asian counties.

**Near Work and Outdoor Activity**

By contrast with previous studies that reported urban–rural differences in schooling and near work,\textsuperscript{18} we found no statistically significant differences in the time spent engaged in near work among children living in the five regions in our study. Similarly, there were no statistically significant differences in the time spent outdoors, which suggests that, overall, outdoor access is not restricted by locality in Sydney, with public open spaces widely available. Children may also travel to access beach areas or national parks.

A slight but statistically significant protective effect from outdoor activity has been reported in studies of childhood myopia.\textsuperscript{13–26} In the present study, the differences in outdoor activity were relatively small (there was a mean difference of 1.4 h/wk between outer suburban and inner city areas). The final multivariate model for myopia also showed statistically significant, though somewhat weaker, effects from outdoor activity (OR, 0.96; 95% CI, 0.95–0.98, for each additional hour per week) by comparison with region (inner city versus outer suburban; OR, 2.5; 95% CI, 1.5–4.1). This suggests that outdoor activity alone is unlikely to be driving the association of myopia with inner city/urban residence.

**Parental Myopia and Ethnicity**

Other possible contributing factors to the higher childhood myopia prevalence in urban compared to suburban samples could be the greater proportion of parents with myopia, differences in socioeconomic status plus differences in ethnic composition. The higher frequency of parental myopia in the inner urban regions and an uneven distribution of higher income earners in parts of Sydney (for example in inner city areas) could have increased the prevalence of childhood myopia. A relatively greater proportion of East Asian children than European Caucasian children living in the inner city/urban regions may also have contributed to higher myopia prevalence.

In stratified analyses for childhood myopia, there were significant regional associations in both European Caucasian and East Asian children. Multivariate analyses that adjusted for socioeconomic status (parental education), parental myopia, and ethnicity showed that region persisted as a significant variable for childhood myopia, confirming that these findings were independent of both parental myopia and ethnicity.

**Housing Density and Housing Type**

We defined region using groupings of population density. This definition also matched housing type, so that in more urban areas, apartment or terrace housing was more prevalent ($\chi^2 < 0.0001$). Housing type was found to be related to myopia, independent of the effects of region, ethnicity, near work, or outdoor activity. We could not, however, find any associations between housing density and myopia in this sample.

**Implication of Findings**

The public health impact from the urban environment on eye health and general health in children may become increasingly important in the longer term, particularly as populations continue to rise and residential areas become increasingly built up. With myopia on the rise in urbanized parts of the world such as Hong Kong, Taiwan, and Singapore, it is unclear whether similar trends of increasing myopia will also be evident in countries undergoing rapid urbanization.

Currently, the intent of treatment for myopia is vision correction, with options including the use of spectacles, contact lens, and refractive surgery. Other treatment options for myopia currently under evaluation in experimental studies include orthokeratology and the use of pharmacologic therapies such as atropine and pirenzepine. In addition to pursuing treatment in myopia, there is a growing need to identify potentially modifiable factors for implementation in primary interventional studies. The current findings could have substantial implications for intervention at the level of the local community in areas such as town planning and residential housing, particularly in areas of low myopia prevalence.

**Strengths and Limitations**

Several factors contribute to the strengths of this study on myopia and the urban environment. Data were collected from a large representative sample of children living in a predominantly urban setting, studying in the same school year, and educated within the same school system. By sampling within these environmental conditions, we were able to minimize possible confounding effects from factors such as education and study. Adjustment for other factors such as outdoor activity and parental myopia was also included in our analyses as a rigorous test of the significance of regional differences. Standardized examination and test procedures used at all schools and the objective measures of refraction (cycloplegia with cyclopentolate) have also strengthened the findings of this study.

In the existing literature on refraction, myopia has been defined using various measurement methods (retinoscopy versus autorefration), using a variety of cutoffs, defined either by spherical equivalent refraction or based on horizontal and vertical meridians. Although myopia can be considered a continuum along the spectrum of refractive error rather than a distinct condition, the Refractive Error Study in Children (RESC)\textsuperscript{27} surveys conducted in China, India, Malaysia, South Africa, and Chile have all used a protocol of cycloplegic autorefration, with spherical equivalent refraction cutoffs defining myopia at $-0.50$ and/or $-1.00$ D.

In our study, myopia was defined in a similar manner, by using spherical equivalent refraction, and tested by autorefration in subjects under cycloglia. This definition, which enables direct comparison with previous studies, could also be more meaningful than a higher cutoff for the purpose of evaluating the early processes affecting eye geometry in myopia, since myopic refractive error under cycloglia, even at $-0.50$ D, could suggest that the growth of the eye has already progressed to a stage beyond emmetropia. As Mutti and Zadnik\textsuperscript{28} have shown, refractive error at a young school age in children is a strong predictor of later myopia. Using $-0.50$ D as a cutoff for myopia in the present study could also provide some indication of those children more likely to be identified as myopic in later life, regardless of the defining cutoff.

One of the limitations of this study was the inability to collect refraction data on nonparticipants, because children with existing refractive errors may have been more likely to participate, which could have resulted in greater statistical significance for some of the associations reported. The relatively high participation rate and the similarity of demography between participants and nonparticipants, however, provide some assurance that this was a fairly representative sample and
that participation bias was only minimal. Although housing density was indirectly assessed in the present study by proximity to other houses, this may have been a fairly unreliable indicator of urbanization, particularly for children residing in apartment housing. Assessment of other factors such as diet, and green space availability and its utilization, could be examined in future studies.

In conclusion, findings from this sample of 12-year-old Australian school children confirm previous reports of higher myopia prevalence for children living in city areas with higher population density. This association was found to be independent of conventional myopia risk factors such as ethnicity, parental myopia, the levels of near work, and outdoor activity. These data provide evidence supporting the hypothesis that certain features of the urban environment may influence the development of myopia in childhood. Further work to characterize which specific aspects of urban living contribute to myopia would be useful.

References