Refractive Error and Visual Impairment in Urban Children in Southern China

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PURPOSE. To assess the prevalence of refractive error and visual impairment in school-age children in a metropolitan area of southern China.

METHODS. Random selection of geographically defined clusters was used to identify children 5 to 15 years of age in Guangzhou. Children in 22 clusters were enumerated through a door-to-door survey and examined in 71 schools and 19 community facilities from October 2002 to January 2003. The examination included visual acuity measurements, ocular motility evaluation, retinoscopy, and autorefraction under cycloplegia and examination of the external eye, anterior segment, media, and fundus.

RESULTS. A total of 5053 children living in 4814 households were enumerated, and 4364 (86.4%) were examined. The prevalence of uncorrected, presenting, and best-corrected visual acuity 20/40 or worse in the better eye was 22.3%, 10.3%, and 0.62%, respectively. Refractive error was the cause in 94.9% of the 2335 eyes with reduced vision, amblyopia in 1.9%, other causes in 0.4%, and unexplained causes in the remaining 2.8%. External and anterior segment abnormalities were seen in 1496 (34.3%) children, mainly minor conjunctival abnormalities. Media and fundus abnormalities were observed in 32 (0.73%) children. Myopia (spherical equivalent of at least −0.50 D in either eye) measured with retinoscopy affected 73.1% of children 15 years of age, 78.4% with autorefraction. The prevalence of myopia was 3.3% in 5-year-olds with retinoscopy and 5.7% with autorefraction. Females had a significantly higher risk of myopia. Hyperopia (+2.00 D or more) measured with retinoscopy was present in 16.7% of 5-year-olds, 17.0% with autorefraction. The prevalence of hyperopia was below 1% in 15-year-olds, with both methods. Astigmatism (cylinder of ≥0.75 D) was present in 33.6% of children with retinoscopy and in 42.7% with autorefraction.

CONCLUSIONS. The prevalence of reduced vision because of myopia is high in school-age children living in metropolitan Guangzhou, representing an important public health problem. One third of these children do not have the necessary corrective spectacles. Effective strategies are needed to eliminate this easily treated cause of significant visual impairment. (*Invest Ophthalmol Vis Sci.* 2004;45:793–799) DOI:10.1167/iovs.03-1051

A global coalition of nongovernmental organizations and the World Health Organization has recently launched the Vision 2020: The Right to Sight initiative. The Vision 2020 strategy for the elimination of avoidable visual impairment and blindness includes the correction of refractive errors. There is thus a need for reliable data to inform the planning and implementation of refractive error screening and treatment programs. Although numerous studies of refractive error have been performed, most were in settings of unknown representation, and because of different measurement methods and nonuniform definitions, comparisons of data are difficult.[1]

In addressing the lack of representative and comparative data, a series of population-based surveys of refractive error and visual impairment in school-age children was initiated, beginning in 1998 using the same protocol.[2] These RESC (Refractive Error Study in Children) surveys were conducted in populations with different ethnic origins and environments: a rural district in eastern Nepal[3]; a rural area near Beijing, China[4]; an urban area of Santiago, Chile[5]; a rural district near Hyderabad in southern India[6]; an urban area of New Delhi, India[7]; and a semirural/urban area of Durban, South Africa.[8] This article reports findings of a seventh such survey, conducted in metropolitan Guangzhou, China.

The Guangzhou study was motivated by interest in obtaining visual impairment and refractive error data in a large urban setting for comparison with that obtained from the RESC survey in the rural part of Shunyi district.[4] Comparative findings provide insight into the growing public health significance of refractive error among school-age children as urbanization continues in China.

METHODS

Sample Selection

Guangzhou, the capital city of Guangdong province, is the economic, cultural, and scientific center of South China, with a population of 9.94 million in the 2000 Census.[9] The Liwan district, one of 10 administrative districts in Guangzhou, was identified for the survey because of its relatively stable population (514,660 in the 2000 Census) and representative demographic and socioeconomic characteristics. District residents are of Han ethnicity (Chinese) and represent a wide socioeconomic spectrum: average annual income per working resident is 14,198 yuan ($1715 US).[9]

Cluster sampling was used to select the study sample. Clusters were defined geographically using Residence Administrative Committees (RACs). The Liwan district is divided into 207 RACs. In creating the sampling frame, RACs with large populations were subdivided and those with small populations were grouped to create clusters with an estimated 200 to 250 eligible children, aged 5 to 15 years. A total of 238 clusters were so defined, with 22 selected randomly (with equal probability) for the study. Based on 2000 Census data, an estimated 5330 eligible children were living in these 22 specific clusters, exceeding the 5200 sample size requirement calculated originally for the

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earlier RESC studies. The original sample size was calculated on the basis of estimating an age-specific prevalence of 22% within a 20% error bound with 95% confidence, with upward adjustment to accommodate nonparticipation (10%) and the cluster sampling design (25%).[2]

Field Operations

Using the 2000 Census, households with eligible children were identified by address and other contact information. These households were then individually visited by personnel from the Guangzhou Bureau of Statistics— up to three times—to verify the name, gender, and birth date of eligible children. During this door-to-door enumeration, the child's current school, grade level, and class information were also recorded—as was the educational level of each parent.

All children of eligible age living in census-identified households for at least 6 months, with or without official residency, were enumerated. Children temporarily absent from the area, those staying in boarding schools, and institutionalized subjects (e.g., those in special schools for the handicapped) were also enumerated. Nonresident visitors and guests were not. Households in buildings constructed after 2000 could not be identified from census information and were not included in the study sample.

During the enumeration interview, a parent or guardian of the child was informed of the study details, including the side effects of pupillary dilation and cycloplegia, given a time schedule for eye examinations, and requested to sign an informed consent form. Only those who agreed to an examination under full cycloplegic dilation were considered to have consented. The enumeration was completed in 1 month, September 2002, by four teams, each with two enumerators and an RAC officer familiar with the local community.

Three days before the eye examinations, a project ophthalmologist (MH or JX) accompanied by an officer from the District Bureau of Education visited schools to obtain their cooperation and to confirm that study children could be located based on the grade and classroom information obtained during the enumeration. Parents who had expressed hesitancy or reluctance to cooperate were invited to a seminar, 1 day before the scheduled examinations, to receive further explanation and motivation regarding study participation.

Eye Examinations

Eye examinations were performed, between October 9, 2002, and January 5, 2003, by two clinical teams, each with one optometrist, three ophthalmic nurses, and one ophthalmologist. Examinations were conducted in schools with 10 or more study children, generally during the week while classes were in session. Other study children were examined on weekends in temporary stations set up in community facilities. Examinations were conducted in 71 schools and 19 community facilities.

The examination process began with testing visual acuity at 4 m using a retroilluminated logarithm of the minimum angle of resolution (LogMAR) chart with tumbling-E optotypes (Precision Vision, La Salle, IL). In children who were wearing glasses, visual acuity was measured both with and without spectacles. Lens power was measured with an autolensometer (LM-970; Nidek Corp., Tokyo, Japan). Ocular motility was evaluated with a cover test at 0.5 and 4.0 m. Corneal light reflex was used to quantify the degree of tropia.

Cycloplegia was induced with 2 drops of 1% cyclopentolate, administered 5 minutes apart, with a third drop administered after 20 minutes. Cycloplegia and pupil dilation were evaluated after an additional 15 minutes. Pupils were considered fully dilated at 6 mm or greater, and cycloplegia was considered complete if light reflex was absent. Refraction was performed first with a streak retinoscope (Welch-Allyn, Skaneateles, NY) and then independently by a second examiner, with a handheld autorefractor (ARK-30; Nidek Corp.). After alignment, the autorefractor produces eight refraction values, each with a machine-calculated confidence index, along with an average weighted value. Subjective refraction was performed on children with unaided visual acuity 20/40 or worse.

The team ophthalmologist evaluated the anterior segment (eyelid, conjunctiva, cornea, iris, and pupil) with a magnifying loupe and performed handheld slit lamp and indirect ophthalmoscopic examination of the lens, vitreous, and fundus. Taking into account all available information, the examining ophthalmologist assigned a principal cause of visual impairment for eyes with uncorrected visual acuity of 20/40 or worse. Refractive error was assigned if acuity improved to at least 20/32 with refractive correction. Further detail regarding examination procedures is available elsewhere.[2]

Each child was provided postmydriatic sunglasses and reading glasses (free of charge) to mitigate discomfort in bright light and difficulties with homework associated with cycloplegic dilation. Children with vision of 20/40 or worse in the better eye and improving with refractive correction were given prescription glasses free of charge. Children requiring medical or surgical treatment beyond what could be provided on site were referred to the Zhongshan Ophthalmic Center (ZOC).

Human subject approval for the original study protocol was obtained from the World Health Organization Secretariat Committee on Research Involving Human Subjects. Both the ethics committee of the ZOC and the Liwan District Bureau of Education and Bureau of Health approved implementation of the study. The protocol adhered to the provisions of the Declaration of Helsinki for research involving human subjects.

Pilot Study

Fieldwork was preceded by training and a pilot exercise, conducted in September 2002 outside of the study area. A total of 280 children from one kindergarten, one primary school, and one secondary school were examined in the pilot, which revealed weaknesses in visual acuity testing and in the organization of the examination process. These deficiencies were successfully addressed before implementation of the main study.

Data Management and Analysis

Household enumeration and clinical examination data forms were reviewed for accuracy and completeness before transfer to ZOC for computer data entry. Measurement data ranges, frequency distributions, and consistency among related measurements were checked with data cleaning programs. Statistical analyses were performed on computer (Stata Statistical Software, Release 8.0; Stata Corp., College Station, TX).[10]

Prevalence rates of visual impairment and blindness using uncorrected (unaided), presenting, and best corrected visual acuity were calculated. The latter measurement was based on subjective refraction for those with reduced uncorrected visual acuity. Thresholds of 20/40 or less, less than 20/63, and 20/200 or less were used in defining visual acuity categories.

Myopia was defined as spherical equivalent refractive error of at least −0.50 D and hyperopia as +2.00 D or more. Children were considered to have myopia if one or both eyes were myopic, hyperopic if one or both eyes were hyperopic, so long as neither eye was myopic, and emmetropic if neither eye was myopic or hyperopic. Age-specific prevalences of myopia and hyperopia were estimated in children with cycloplegia in both eyes. The association between myopia or hyperopia and the child's age and gender, as well as parental education, was explored by logistic regression. Parental education reflected the parent with the highest level of schooling and was categorized as no schooling, primary, junior high, senior high, and university.

Confidence intervals were calculated with adjustment for clustering effects associated with the sampling design.[10] Cluster design effects are represented by a ratio—termed deff— comparing the estimate of variance actually obtained with the (generally smaller) variance that would have been obtained had simple random sampling been used.

TABLE 1. Enumerated and Examined Population by Age

Enumerated Population			Examined Population	
Age* (y)	***n* (%)**	**Percent Examined**	**Age† (y)**	***n* (%)**
5	470 (9.3)	73.2	5	271 (6.2)
6	324 (6.4)	84.3	6	295 (6.8)
7	393 (7.8)	89.1	7	326 (7.5)
8	446 (8.8)	89.2	8	394 (9.0)
9	468 (9.3)	90.4	9	398 (9.1)
10	434 (8.6)	91.7	10	415 (9.5)
11	494 (9.8)	88.5	11	427 (9.8)
12	537 (10.6)	86.8	12	454 (10.4)
13	606 (12.0)	88.5	13	498 (11.4)
14	525 (10.4)	88.2	14	510 (11.7)
15	356 (7.1)	77.5	15	376 (8.6)
All	5053 (100.0)	86.4	All	4364 (100.0)

* Age at the time of enumeration.
† Age at examination.

Pair-wise interactions between regression model variables were assessed simultaneously using a Wald F test[10] and were considered significant at $P < 0.10$.

Quality Assurance

Quality assurance was an integral aspect of the study. Nine schools (two kindergartens, four primary, and three secondary) and two community facilities, scheduled throughout the course of the study, were identified for interobserver reproducibility testing. Children with uncorrected visual acuity 20/40 or worse (either eye) and 10% of those with normal/near normal vision, were subjected to repeat testing for uncorrected visual acuity, retinoscopy, and autorefraction by a second examiner.

A total of 361 children were subjected to quality assurance evaluations. Of right eye measurements, 139 (38.5%) differed by 1 line, 13 (3.6%) differed by 2 lines, and none differed by more than 2 lines. Of left eyes, 140 (38.8%) differed by 1 line, 11 (3.0%) by 2 lines, and one (0.3%) by 3 lines. The κ statistics were 0.53 for both right and left eyes. With a weighted κ, giving half weight to 1-line disagreement, the respective statistics were 0.71 and 0.72

Mean test–retest differences (the first measurement minus the second one) for cycloplegic retinoscopy were -0.015 ± 0.231 D (SD) for right eyes and $+0.008 \pm 0.208$ D for left eyes. Neither difference was significantly different from zero (paired *t*-test, $P = 0.212$ and $P = 0.429$). The 95% upper and lower limits of agreement around mean differences[11] were -0.469 to $+0.438$ D for right eye measurements and -0.399 to $+0.416$ D for left eyes. Reproducibility for cycloplegic autorefraction was comparable, with mean test–retest differences of -0.016 ± 0.235 D for right eyes and $+0.002 \pm 0.235$ D for left eyes. Again, neither of these differences was statistically significant ($P = 0.189$ and $P = 0.867$). The 95% limits of agreement for cycloplegic autorefraction were -0.477 to $+0.444$ D and -0.458 to $+0.481$ D, respectively.

RESULTS

Study Population

Within the 22 study clusters, 5491 households were identified as having eligible children based on the 2000 census. Of these, 454 were found unoccupied or demolished because of construction in the area. Of the remaining 5037 households, 223 (4.4%) were without eligible children, 4585 (91.0%) had one child, and 229 (4.5%) had two or more.

The age distribution of the 5053 enumerated children is shown in Table 1. Boys constituted 51.9% of the total, with age-specific percentages ranging from 47.1% in 8-year-olds to 55.3% in 6-year-olds.

A total of 4364 children were examined, representing 86.4% of those enumerated. Cluster-specific response rates ranged from 78.7% to 91.7%. Examination response was 85.8% in boys and 87.0% in girls. The examined population, distributed by age at examination (which is used in subsequent analyses) is shown in Table 1.

Visual Acuity

Visual acuity findings are presented in Table 2. Measurement was not possible in 5 of the 4364 examined children. Uncorrected visual acuity of 20/40 or worse in the better eye was found in 971 (22.3%) children, including 35 (0.8%) blind in both eyes. Visual acuity differed between boys and girls, with girls having poorer vision (Kolmogorov-Smirnov test, $P < 0.001$). Nine hundred eight children said they wore glasses, but only 800 were wearing them (Table 2). Of those with visual acuity 20/40 or worse in the better eye, 640 (65.9%) were wearing glasses, and another 61 said they had glasses but were not wearing them. Four hundred forty-four (10.3%) children presented with visual impairment of 20/40 or worse in the better eye. With best measured acuity, this number decreased to 27 (0.62%), with no one blind.

Cycloplegic Dilation

Pupillary dilation of at least 6 mm and the absence of light reflex were achieved in 3911 (89.6%) right eyes, absent light reflex without full dilation was achieved in 437 (10.0%) eyes, and dilation only in 3 (0.07%) eyes, leaving 13 (0.3%) right eyes that did not satisfy either criterion. In left eyes, the respective numbers were 3894 (89.2%), 455 (10.4%), and 4 (0.09%), with 11 (0.25%) eyes that did not satisfy either criterion. In one

TABLE 2. Distribution of Uncorrected, Presenting, and Best Corrected Visual Acuity

Visual Acuity Category	Uncorrected Visual Acuity *n* (%; 95% CI)	Wearing Glasses *n* (%)*	Presenting Visual Acuity *n* (%; 95% CI)	Best Visual Acuity *n* (%; 95% CI)
≥20/32 both eyes	2995 (68.7;66.6–70.8)	73 (2.4)	3466 (79.5;77.9–81.2)	4267 (97.9;97.4–98.4)
≥20/32 one eye only	393 (9.02;8.03–10.0)	87 (22.1)	446 (10.2;9.15–11.3)	65 (1.49;1.16–1.83)
≤20/40 to ≥20/63 better eye	572 (13.1;11.9–14.3)	286 (50.0)	391 (8.97;8.03–9.91)	24 (0.55;0.35–0.82)†
≤20/80 to ≥20/160 better eye	364 (8.35;7.54–9.16)	319 (87.6)	55 (1.26;0.99–1.54)	3 (0.07;0.01–0.20)†
≤20/200 better eye	35 (0.80;0.51–1.09)	35 (100.0)	1 (0.02;0.00–0.13)†	0
All	4359 (100.0)	800 (18.4)	4359 (100.0)	4359 (100.0)

* Percent of the number within each visual acuity category based on uncorrected vision.
† Confidence intervals were calculated using the exact binomial distribution instead of the normal approximation. Cluster design effects, ranging from 0.757 to 1.085, are not reflected in the confidence intervals for exact binomial estimates. (Design effects ranging from 0.607 to 2.009 were taken into account in calculating confidence intervals for estimates based on the normal approximation.)

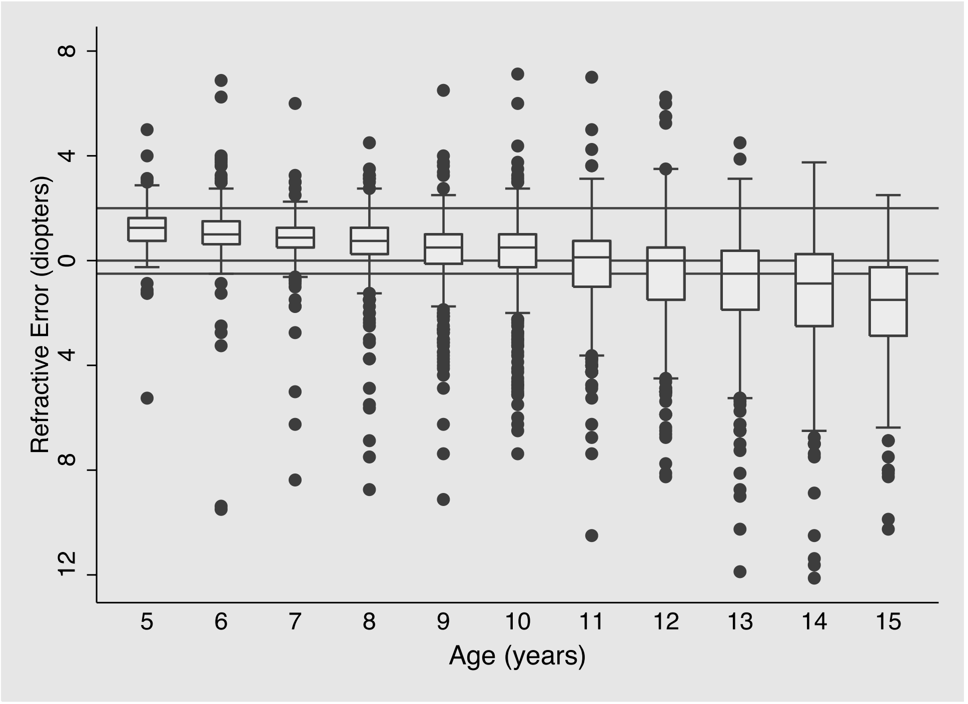

FIGURE 1. Distribution of spherical equivalent refractive error in right eyes by age, as measured with cycloplegic retinoscopy. *Horizontal lines* at +2.00 diopters and −0.50 diopter represent definition thresholds for hyperopia and myopia, respectively. Each *box* extends from the 25th to the 75th percentile of the age-specific distribution, the interquartile range, with the *bar* inside representing the median. *Whiskers* extend to the lower and upper extremes, defined as the 25th percentile minus 1.5 times the interquartile range and the 75th percentile plus 1.5 times the interquartile range. One −21.75-D measurement for a child of age 15 is not shown.

child, cycloplegic dilation was not possible, because of a lack of cooperation. Dilation was not attempted for two right eyes (congenital microphthalmia and pseudophakia) and for one left eye (ocular atrophy). For the remaining 10 right eyes and 9 left eyes, cycloplegic dilation was attempted without success.

Refractive Error

For the 4348 right eyes with cycloplegia (absent light reflex), retinoscopy measurements were available for 4347 and autorefraction for 4322. For the 4349 left eyes with cycloplegia, retinoscopy measurements were available for all 4349 and autorefraction for 4323. The failure to achieve autorefraction was primarily because of media opacities and a temporary machine malfunction.

Spherical equivalent (SE) refractive error varied with age, from a median of +1.25 D in right eyes of 5-year-olds to −1.50 D in 15-year-olds, as measured with cycloplegic retinoscopy (Fig. 1). Across all ages, median SE refractive error was +0.375 D in boys and +0.25 D in girls; mean values were −0.142 ± 1.837 D and −0.273 ± 2.032 D, respectively. With cycloplegic autorefraction, median SE refractive error changed from +1.00 D in 5-year-olds to −1.50 D in 15-year-olds. Overall, the median SE refractive error was +0.125 D in both boys and girls, with respective mean values of −0.299 ± 1.820 D and −0.422 ± 1.974 D. Findings in left eyes were similar for both retinoscopy and autorefraction.

For children 5 years of age, the prevalence of hyperopia measured with retinoscopy was 16.7% (95% CI, 12.5%–20.9%), and 17.0% (95% CI, 12.8%–21.3%) with autorefraction (Table 3). Hyperopia decreased to less than 1% in the 15 year cohort, with both measurement methods. The prevalence of myopia, measured with retinoscopy, increased from 3.3% (95% CI, 0.4%–6.3%) in 5-year-olds to 73.1% (95% CI, 68.0%–78.2%) in 15-year-olds: 69.3% in 15 year-old boys and 77.5% in girls. Categorized by severity in the worse eye, myopia in the 15-year-old cohort was: 4.8%, −6.00 D or less; 37.1%, −5.875 to −2.00 D; 22.0%, −1.875 to −1.00 D; and 9.1%, −0.875 to −0.50 D. With autorefraction, the prevalence increased from 5.7% (95% CI, 2.3%–9.0%) in 5-year-olds to 78.4% (95% CI, 74.5%–82.2%) in 15-year-olds: 73.4% in boys and 83.2% in girls. The severity of myopia with autorefraction was distributed similar to that with retinoscopy.

In logistic regression modeling with parental education (an ordinal variable) and the child's age and gender as covariates, myopia measured with autorefraction was associated with older age (odds ratio [OR], 1.52; 95% CI, 1.48–1.56), female gender (OR, 1.29; 95% CI, 1.11–1.51), and higher parental education (OR, 1.22; 95% CI, 1.05–1.42). Retinoscopy produced essentially the same results. In multiple logistic regression for hyperopia, the child's age was statistically significant (OR, 0.77; 95% CI, 0.73–0.81), reflecting a lower prevalence of hyperopia with increasing age. There was also an inverse association with parental education (OR, 0.81; 95% CI, 0.66–0.98). Gender was not statistically significant ($P = 0.233$). With retinoscopy, only the child's age was statistically significant ($P = 0.001$).

Astigmatism of at least 0.75 D in cylinder was found in 21.4% of right eyes and in 29.6% of left eyes with retinoscopy (Table 4). With autorefraction, the percentages were 26.3% and 34.8%, respectively. The higher prevalence found with autorefraction was because of mild/moderate forms of astigmatism. Astigmatism in either eye was present in 33.6% of children measured with retinoscopy and in 42.7% with autorefraction. In multiple logistic regression modeling with age and gender as covariates, astigmatism was associated with younger age (OR, 0.96; 95% CI, 0.94–0.98) and female gender (OR, 1.16; 95% CI, 1.03–1.29) with retinoscopy measurements. Neither was significant with autorefraction. For astigmatism 2.00 D or greater, age and gender were not statistically significantly associated with either retinoscopy or autorefraction measurements.

Measurement Agreement

Although retinoscopy and autorefraction measurements correlated highly (Pearson correlation of 0.988 for both right and left eyes), autorefraction was systematically more negative (less positive). The mean difference was −0.157 ± 0.301 D for right

TABLE 3. Prevalence of Ametropia in Either Eye by Age

Age (y)	Hyperopia*		Myopia†	
	Retinoscopy	Autorefraction	Retinoscopy	Autorefraction
5	16.7;12.5–20.9	17.0;12.8–21.3	3.3; 0.4–6.3	5.7; 2.3–9.0
6	14.6; 9.7–19.6	10.7; 6.4–15.1	2.7; 0.8–4.7	5.9; 2.6–9.2
7	7.1; 3.5–10.6	4.0; 1.3–6.7	6.8; 4.4–9.2	7.7; 4.7–10.8
8	10.2; 6.7–13.7	7.1; 3.9–10.4	13.7;10.2–17.2	14.0;10.4–17.6
9	4.5; 2.6–6.5	3.8; 2.0–5.6	22.0;18.4–25.5	25.9;22.0–29.8
10	5.8; 3.7–7.8	4.6; 2.1–7.1	25.3;20.5–30.1	30.1;24.4–35.8
11	4.2; 2.0–6.4	3.5; 1.7–5.6	39.1;33.8–44.4	41.7;37.3–46.1
12	2.2; 0.6–3.8	2.0; 0.5–3.6	45.6;40.9–50.3	49.7;44.7–54.6
13	3.4; 1.5–5.4	3.4; 1.6–5.2	55.8;50.3–61.4	57.4;52.1–62.6
14	2.2; 1.0–3.4	1.2; 0.3–2.1	62.6;59.4–65.8	65.5;62.4–68.5
15	0.8; 0.0–1.7	0.5; 0.0–1.3	73.1;68.0–78.2	78.4;74.5–82.2
All	5.8; 5.3–6.3	4.6; 4.4–4.9	35.1;33.2–36.9	38.1;36.3–39.8

Data are prevalence in percent, followed by the 95% confidence interval.

* Cluster design effects ranged from 0.745 to 1.431 with retinoscopy and from 0.764 to 1.436 with autorefraction.

† Cluster design effects ranged from 0.506 to 1.653 with retinoscopy and from 0.477 to 1.491 with autorefraction.

eye measurements and −0.146 ± 0.303 D for left eyes, both statistically significant (paired *t*-tests, $P < 0.001$). The 95% limits of agreement were −0.747 to +0.432 D for right eyes and −0.739 to +0.447 D for left eyes. The systematic difference between retinoscopy and autorefraction was present across both negative and positive measurements.

Ocular Abnormalities

Tropia at near fixation was present in 85 (1.9%) children and in 131 (3.0%) with distance fixation (one child could not be evaluated). Tropia was mostly exotropia: 80% with near and 86% with distant fixation. With near fixation, 83.5% of tropia was 15° or less and 87.0% with distant fixation.

Exterior and anterior segment abnormalities were observed in 1496 (34.3%) of the 4364 examined children. Eyelid abnormalities, mainly clinically insignificant epicanthal folds, were observed in 399 (5.0%) eyes of 220 children. Conjunctival abnormalities, mainly follicles, papillary hypertrophy, and concretions, were seen in 1949 (30.1%) eyes of 1312 children. Corneal abnormalities were present in 17 (0.25%) eyes of 11 children. Pupillary abnormalities were noted in 34 (0.69%) eyes of 30 children. Other anterior segment abnormalities were observed in 11 (0.18%) eyes of 8 children.

Media and fundus abnormalities were observed in 32 (0.73%) children. Lenticular abnormalities (intraocular lens, posterior capsule opacification [PCO]) were present in eight (0.14%) eyes of six children. Vitreous abnormalities were seen in eight (0.14%) eyes of six children. Fundus abnormalities were present in 40 (0.57%) eyes of 25 children.

Cause of Visual Impairment

Reduced vision was overwhelmingly caused by refractive error. For the 1364 children with visual acuity 20/40 or worse in one or both eyes, 1272 (93.3%) attained acuity 20/32 or better in both eyes with refractive correction (Table 2). Another 32 had correctable refractive error in one eye with an uncorrectable cause in the fellow eye, for a total of 1304 (95.6%) children with refractive error as the cause of impairment in one or both eyes, as shown in Table 5. Amblyopia, satisfying explicit criteria,[2] was the cause of visual impairment in 38 (2.8%) children: 8 with a tropia; 20 with anisometropia 2.00 SE diopters or more; 3 with hyperopia of 6.00 SE diopters or more; 4 with tropia and anisometropia; and 3 with anisometropia and hyperopia. Other causes of vision loss were uncommon. In 65 eyes of 48 children, there was no explanation for reduced vision, including 46 eyes of 34 children where amblyopia was considered the principal cause, even though none of the explicit criteria were met.

Discussion

More than 5000 children were enumerated in this survey of urban, school-aged children in the Liwan district of Guangzhou. Excluding the apparent undersampling of 15-year-olds and the overabundance of 5-year-olds, there was no statistically significant difference between the age distribution of the sample and that from the 2000 Census for the district as a whole (χ^2 goodness of fit, $P = 0.116$). The deficit of 15-year-olds was because of an inconsistency in the way age, in years, was

TABLE 4. Prevalence of Astigmatism

Cylinder Value (D)	Retinoscopy			Autorefraction		
	Right Eye	Left Eye	Children*	Right Eye	Left Eye	Children*
<0.75	3421 (78.6)	3065 (70.4)	2888 (66.4)	3186 (73.7)	2821 (65.2)	2475 (57.3)
≥0.75 to <2.00	673 (15.5)	905 (22.6)	1092 (25.1)	887 (20.5)	1215 (28.1)	1481 (34.3)
≥2.00	256 (5.9)	303 (7.0)	368 (8.5)	252 (5.8)	291 (6.7)	366 (8.5)
All	4350 (100.0)	4353 (100.0)	4348 (100.0)	4325 (100.0)	4327 (100.0)	4322 (100.0)

Data are number of children with percentage of total in parentheses.

* Astigmatism in children is categorized using the worse eye.

Table 5. Causes of Uncorrected Visual Acuity 20/40 or Worse

Cause	Eyes with Uncorrected Visual Acuity 20/40 or Worse (*n*, %)		Children with Visual Acuity 20/40 or Worse (*n*, %) (One or Both Eyes)*	Percent Prevalence in the Population (One or Both Eyes)*
	Right Eye	Left Eye		
Refractive error†	1106 (95.1)	1109 (94.6)	1304 (95.6)	29.88
Amblyopia‡	21 (1.8)	24 (2.0)	38 (2.8)	0.87
Corneal opacity	0 (0.0)	1 (0.1)	1 (0.1)	0.02
Cataract\PCO	1 (0.1)	1 (0.1)	1 (0.1)	0.02
Retinal disorder	2 (0.2)	3 (0.3)	3 (0.2)	0.07
Other causes	1 (0.1)	1 (0.1)	2 (0.1)	0.05
Unexplained cause§	32 (2.8)	33 (2.8)	48 (3.5)	1.10
Any cause	1163 (100.0)	1172 (100.0)	1364 (100.0)	31.30

* Children with visual acuity 20/40 or worse in both eyes may represent two different causes of reduced vision—a different cause for each eye. Accordingly, the total of 1397 children across all specific causes exceeds the 1364 with "any cause" of impairment. Similarly, the total for the cause-specific prevalences exceeds the "any cause" prevalence.

† Refractive error was assigned as the cause of reduced vision for all eyes correcting to 20/32 or better with subjective refraction, even if other contributing disease was present.

‡ Includes only cases meeting the defined tropia, anisometropia, or hyperopia criteria for amblyopia.

§ Includes 46 eyes of 34 children in whom the examining ophthalmologist concluded that amblyopia was the principal cause of impairment, even though the amblyopia criteria were not met.

defined during the enumeration versus the way it is defined here and in the other RESC surveys. Because children between the ages of 15 years and 6 months to 16 years and 6 months are considered 16-year-olds by the Bureau of Statistics, households with children within 6 months of their 16th birthdays were not identified for enumeration (except those where younger children of eligible age were also in the household). The apparent excess in enumerated 5-year-olds cannot be explained.

The overall examination response rate (86.4%) was very good, considering that the survey was conducted in a densely populated metropolitan area with middle and upper-middle class families. The involvement of district government officials, the cooperation of district schools, a widely available public transportation system, and convenient examination schedules contributed to this success. Providing postmydriatic sunglasses and reading glasses, without cost, helped alleviate hesitancy in participation caused by concern about side affects associated with pupillary dilation and cycloplegia.

Because it was not possible to arrange examinations in school for a disproportionate number of 5- and 15-year-olds, the response in these age cohorts was diminished. Organizational arrangements and the examination process were more effective in school environments than in community facilities. Many 5-year-olds were invited to community-based facilities for examination, because they were not yet enrolled in school or were in widely dispersed private kindergartens. Similarly, 15-year-olds who had already finished secondary school or had been upgraded to higher level schools outside of the district could not be offered an examination in a school setting.

The 22.3% prevalence of visual impairment (20/40 or worse in the better eye) was much higher than the 8.2% found in the RESC survey conducted in Shunyi district.[4] (When age-adjusted to the Liwan study population, the Shunyi prevalence is 8.9%.) With best corrected vision, however, the prevalence of impairment is comparable—below 1% in both districts. Clearly, the prevalence of refractive error is accountable for essentially all the difference in visual impairment between the rural Shunyi and urban Liwan populations.

Given that ethnic origins, culture, and language are comparable between Shunyi and Liwan districts, environmental factors, such as accommodative effort associated with schooling intensity, must be influencing the development and progression of myopia.[12–17] A differential in refractive impairment between urban and rural populations of similar ethnicity was also observed in India.[6,7] The contrast between city and rural environments is also evidenced by major differences observed in the prevalence of conjunctival abnormalities. In metropolitan Liwan, conjunctival abnormalities were seen in 30.1% of children versus 2.2% in rural Shunyi.[4] Air pollution in Guangzhou is thought to be a likely factor in this dramatic difference.

Notwithstanding the association between reduced refractive error and a rural environment, refractive error was the most common cause of visual impairment across all seven of the RESC studies.[3–8] Refractive error accounted for more than half of all visual impairment even in the rural Nepal and rural India surveys. Amblyopia, retinal disorders, and corneal opacity were the next most common vision impairing conditions—generally in that order.

Visual acuity and refractive measurements were shown to be reliable. Test–retest reproducibility was good for visual acuity testing with only 3.5% of all measurements differing by two or more lines. Reproducibility of cycloplegic retinoscopy and autorefraction was also found to be good in test–retest evaluations—within 0.50 D for 95% of measurements, with statistically insignificant mean differences. Because autorefraction generally produced more negative measurements—approximately 0.15 D across the refractive error range for both right and left eyes—the prevalence of myopia in all age groups was consistently higher when measured with autorefraction. An even greater tendency toward more negative measurements with autorefraction was observed in the Shunyi study.[4]

The notable upward trend for myopia beginning with the 7- to 8-year-old cohort coincides with the age at which schooling with intensive near work begins. Another upward trend is apparent at 11 to 12 years of age, around the start of secondary school and puberty. A similar pattern was also present in Shunyi district.[4] Intensive screening programs and the provision of spectacles should be targeted to these specific age groups, particularly if resources to conduct screening for all ages are limited. The need for such programs is evidenced by the fact that only two thirds of children with visual acuity 20/40 or worse in the better eye were wearing corrective spectacles. In Shunyi district it was only 28.8%! Further investigation is needed to gain better understanding of the obstacles to obtaining the necessary spectacles. Awareness of vision problems and cost are likely factors.

To our knowledge, this study is the first to provide population-based data on the prevalence of visual impairment and refractive errors in school-aged children in a large metropolitan area in China. The Shunyi district survey was the first conducted in a rural population. Although such data exist for Chinese school children living outside of China,[18] previous studies within Mainland China were based on convenience samples taken from schools or eye clinics.[19,20]

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