Refractive Error and Visual Impairment in School-Age Children in Gombak District, Malaysia

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Purpose: To assess the prevalence of refractive error and visual impairment in school-age children in Gombak District, a suburban area near Kuala Lumpur city.

Design: Population-based, cross-sectional survey.

Participants: Four thousand six hundred thirty-four children 7 to 15 years of age living in 3004 households.

Methods: Random selection of geographically defined clusters was used to identify the study sample. Children in 34 clusters were enumerated through a door-to-door survey and examined in 140 schools between March and July 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.

Main Outcome Measures: Distance visual acuity and cycloplegic refraction.

Results: The examined population was 70.3% Malay, 16.5% Chinese, 8.9% Indian, and 4.3% of other ethnicity. The prevalence of uncorrected (unaided), presenting, and best-corrected visual impairment (visual acuity ≤20/40 in the better eye) was 17.1%, 10.1%, and 1.4%, respectively. More than half of those in need of corrective spectacles were without them. In eyes with reduced vision, refractive error was the cause in 87.0%, amblyopia in 2.0%, other causes in 0.6%, and unexplained causes in 10.4%, mainly suspected amblyopia. Myopia (spherical equivalent of at least −0.50 diopter [D] in either eye) measured with retinoscopy was present in 9.8% of children 7 years of age, increasing to 34.4% in 15-year-olds; and in 10.0% and 32.5%, respectively, with autorefraction. Myopia was associated with older age, female gender, higher parental education, and Chinese ethnicity. Hyperopia (≥2.00 D) with retinoscopy varied from 3.8% in 7-year-olds, 5.0% with autorefraction, to less than 1% by age 15, with either measurement method. Hyperopia was associated with younger age and “other” ethnicity. Astigmatism (≥0.75 D) was present in 15.7% of children with retinoscopy and in 21.3% with autorefraction.

Conclusions: Visual impairment in school-age children in urban Gombak District is overwhelmingly caused by myopia, with a particularly high prevalence among children of Chinese ethnicity. Eye health education and screening may help address the unmet need for refractive correction. *Ophthalmology 2005;112:678–685 © 2005 by the American Academy of Ophthalmology.*

Worldwide, uncorrected refractive error is increasingly being recognized as a significant cause of avoidable visual disability, as evidenced by its inclusion in the priority areas of Vision 2020: The Right to Sight—a global initiative launched by a coalition of nongovernmental organizations and the World Health Organization.[1] Uncorrected refractive error seems to be an important cause of low vision in Malaysia. Based on a national survey in 1996 among Malaysians of all ages, 48% of those presenting with visual acuity worse than 20/63 in the better eye, and no evidence of cataract with torch light examination, improved to at least 20/63 with a pinhole.[2]

Studies of refractive error have also been carried out in schools in Kuala Lumpur. In a 1987 study in 3 schools, the prevalence of myopia (spherical equivalent refractive error of at least −0.50 diopter [D] in the right eye with noncycloplegic retinoscopic refraction) in Malays 7 to 8 years of age was 4.3%, and it was 25.6% in those 15 to 16 years.[3] In 1990, a similar study was conducted in Chinese children in 4 schools, where the prevalence of myopia increased from 24% in those 6 to 8 years to 50% in those 15 to 16 years.[4] In 2000, Indian children in 3 schools were examined by similar methods; myopia prevalence was 16% for those 7 to 12 years of age and 22% for those 13 to 18 years. (Saadah MA. Visual disorders among Indian schoolchildren. Paper

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Although refractive error studies have been carried out in Malaysia and elsewhere, different measurement methods and nonuniform definitions generally make comparisons of findings difficult.[5] To address the lack of strictly comparable, representative data, a series of population-based surveys in children 5 to 15 years of age was initiated in 1998.[6] By use of the same protocol, these Refractive Error Study in Children (RESC) surveys were conducted in populations with different ethnic origins and environmental settings: rural Jhapa District in eastern Nepal[7]; semirural Shunyi District, near Beijing, China[8]; La Florida, an urban area of Santiago, Chile[9]; rural Mahabubnagar District near Hyderabad, in Southern India[10]; an urban area of New Delhi, India[11]; a semirural/urban area of Durban, South Africa[12]; and an urban area of Guangzhou, China.[13]

Malaysia is a multiracial country consisting of Malays (65%), Chinese (26%), Indians (8%), and various other minorities (1%).[14] It provides the opportunity to study refractive error among different ethnic groups living in a similar geographic setting. The survey in Gombak District was motivated by this opportunity and interest in obtaining data for comparison with earlier RESC surveys, particularly those in China and India, where populations are of ethnicity similar to those in Malaysia but with different living conditions. This article reports on findings from the RESC survey in Gombak district, the first to provide population-based data on the prevalence of refractive error and visual impairment in school-age children in Malaysia.

Materials and Methods

Sample Selection

Gombak District is 1 of 9 districts in the state of Selangor and part of the metropolitan Kuala Lumpur area. The district has an urban population representative of the multiethnicity of Malaysia. The Gombak District population was 553 410 in the 2000 Census—14% of the total Selangor population—with 58.7% Malay, 26.0% Chinese, 12.6% Indian, and 1.9% other minorities.[14] The district has 1 tertiary government hospital (Hospital Selayang), 1 secondary government hospital, 2 private hospitals, 10 health clinics, and 6 village clinics. The Department of Ophthalmology at the Selayang Hospital served as the study headquarters.

A random sample of eligible children from the district was obtained with cluster sampling. Clusters were defined geographically by grouping enumeration blocks, contiguous areas created by the Malaysia Department of Statistics for census-taking purposes. A total of 365 clusters were defined, and 25 were randomly selected (with equal probability) to produce an expected study sample of 500 for each year of age. This exceeded the originally calculated RESC sample size of 472, which was based on estimating a prevalence of 22% within a 20% error bound with 95% confidence and adjustment to accommodate nonparticipation (10%) and cluster sampling (25%).[6] Recognizing the difficulty in measuring visual acuity in young children without schooling experience,[7,9–12] it was decided not to include 5- and 6-year-olds in the Gombak survey.

Field Operations

Enumeration of eligible children was carried out by field workers from the Department of Statistics experienced in census taking and familiar with the Gombak area. Enumerators were given training in the purpose and methods of the study. Lists of living quarters for the selected enumeration blocks (clusters) and detailed maps from the 2000 Census were used in the enumeration process. Living quarters established after the 2000 Census were included in the enumeration. Households sharing the same living quarters were identified separately.

Each household was contacted up to 3 times, if necessary, to obtain an interview with an adult family member. During this door-to-door enumeration, the study purpose was explained and an informative pamphlet left with the interviewee. The ethnicity of the father and years of schooling for each parent were recorded. Name, age, and gender of each eligible child were obtained, along with the child's years of schooling, current school, and grade/class information. Children temporarily absent from the community were included in the enumeration, but institutionalized children and those away from home for 6 months or more were not. Nonresident visitors were also excluded. Written consent for each child was obtained from a parent or guardian.

Families were informed that eye examinations would be conducted in schools, generally where the child was in attendance. In preparation for the examinations, project staff visited schools 2 weeks in advance. Facilities were inspected to ensure suitability for the examination process. Teachers were given the list of study children and asked to remind children who usually wore eyeglasses to bring them to the examination. Children with contact lenses were requested to wear their glasses, instead of contacts, on the examination day. In schools with fewer than 10 study children, teachers were to send study children to a nearby school for the ocular examination.

Clinical Examination

Eye examinations were carried out 5 days a week by 2 clinical teams. Each team consisted of 2 ophthalmologists, 2 optometrists, and 2 ophthalmic assistants.

Visual acuity measurements at 4 m using a retroilluminated logarithm of the minimum angle of resolution chart with tumbling-E optotypes (Precision Vision, La Salle, IL) were performed by an optometrist. For children wearing glasses, visual acuity was measured both with and without them. Lens power was measured with an auto-lensometer (LM-970; Nidek Corporation, Tokyo, Japan). Ocular motility was evaluated with a cover test at 0.5 and 4.0 m, by an ophthalmologist, with corneal light reflex used to quantify the degree of tropia.

Cycloplegia was induced with 2 drops of 1% cyclopentolate, administered 5 minutes apart by ophthalmic assistants, with a third drop administered after 20 minutes. Cycloplegia and pupil dilation were evaluated after an additional 15 minutes. Pupillary dilation of 6 mm or more with absence of light reflex was considered complete cycloplegia.

Refraction was performed first with a streak retinoscope (Welch-Allyn, Skaneateles, NY) and then, independently, by a second optometrist with a handheld autorefractor (Retinomax K-Plus; Nikon, Tokyo, Japan). Subjective refraction was performed on children with unaided visual acuity 20/40 or worse in either eye.

A team ophthalmologist evaluated the external eye and anterior segment (eyelid, conjunctiva, cornea, iris, and pupil) with a magnifying loupe and performed handheld slit-lamp and indirect ophthalmoscopic examination of the media and fundus. The ophthalmologist assigned a principal cause of visual impairment for eyes with uncorrected visual acuity 20/40 or

Table 1. Enumerated and Examined Population by Age, Gender, and Ethnicity

	Enumerated Population		Examined Population
	No. (%)	Percent Examined	No. (%)
Age (yrs)*			
7	701 (12.7)	84.2	590 (12.7)
8	731 (13.2)	84.3	616 (13.3)
9	672 (12.2)	85.6	575 (12.4)
10	693 (12.5)	85.0	589 (12.7)
11	641 (11.6)	86.9	557 (12.0)
12	615 (11.1)	86.8	534 (11.5)
13	553 (10.0)	77.9	431 (9.3)
14	517 (9.4)	81.4	421 (9.1)
15	405 (7.3)	79.3	321 (6.9)
Gender			
Male	2844 (51.4)	82.8	2354 (50.8)
Female	2684 (48.6)	85.0	2280 (49.2)
Ethnicity			
Malay	3872 (70.0)	84.1	3257 (70.3)
Chinese	917 (16.6)	83.3	764 (16.5)
Indian	514 (9.3)	80.2	412 (8.9)
Other	225 (4.1)	89.3	201 (4.3)
All	5528 (100.0)	83.8	4634 (100.0)

*Age at the time of examination; for those not examined, age corresponds to that at the time of enumeration.

worse. (Refractive error was assigned routinely if acuity improved to at least 20/32 with refractive correction.)

Examination procedure details have been described elsewhere.[6]

Children with vision that improved with refraction were prescribed and provided with free spectacles. Children needing medical or surgical treatment were referred to the eye clinic at Selayang Hospital.

Review Board Approval

Human subject research approval for the RESC study protocol was obtained from the World Health Organization Secretariat Committee on Research Involving Human Subjects. The Ethical Committee of the Standing Committee for Medical Research, Malaysia Ministry of Health approved the implementation of the study in Gombak District. The research protocol adhered to the provision of the Declaration of Helsinki for research involving human subjects.

Pilot Study

Fieldwork was preceded by training and a pilot exercise involving 294 children from 2 nonstudy clusters. The pilot revealed weaknesses in the reliability of visual acuity measurements as performed by research assistants. This deficiency was successfully addressed in a second pilot exercise using trained optometrists.

Data Management and Analysis

Household enumeration and clinical examination data forms were reviewed in the field for accuracy and completeness before transfer to Selayang Hospital for computer data entry. Measurement data ranges, frequency distributions, and consistency among related measurements were checked with data cleaning programs.

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 in those with reduced uncorrected visual acuity. Normal/near-normal visual acuity was defined as acuity of $\geq$20/32, visual impairment as $\leq$20/40, and (legal) blindness as $\leq$20/200.

Myopia was defined as spherical equivalent refractive error of at least -0.50 D and hyperopia as $+2.00$ D or more. Refractive error data are presented only for eyes with successful cycloplegic dilation. Children were considered myopic if 1 or both eyes were myopic; hyperopic if 1 or both eyes were hyperopic, so long as neither eye was myopic; and emmetropic if neither eye was myopic or hyperopic. Estimates of the prevalence of myopia and hyperopia were based only on children with successful cycloplegic dilation in both eyes. The association between myopia/hyperopia and the child's age and gender, as well as parental education (based on the parent with the highest level of schooling), and ethnicity was explored using logistic regression.

Statistical analyses were performed using Stata Statistical Software, Release 8.0.[15] Confidence intervals and P values (significant at the $P<0.05$ level) were calculated with adjustment for clustering effects associated with the sampling design. Cluster design effects, represented by a ratio (termed, deff), which compares the estimate of variance actually obtained with the generally smaller variance that would have been obtained had simple random sampling been used, are reported. Pairwise interactions between regression model variables were assessed simultaneously using a Wald F test and considered significant at the $P<0.10$ level.

Quality Assurance

Quality assurance was monitored throughout the study in 30 schools (21 primary and 9 secondary schools) identified in advance for interobserver reproducibility testing. Children with uncorrected visual acuity of 20/40 or worse (either eye) and approximately 10% of other children had repeat evaluations of uncorrected visual acuity, retinoscopy, and autorefraction. The repeat evaluations were conducted, independently, by optometrists who were blinded as to findings from the initial testing.

A total of 647 children, 14.0% of those examined and distributed across all ages, were subjected to quality assurance evaluations. Reproducibility of visual acuity measurements was good, with unweighted Kappa statistics of 0.81 for right eyes and 0.79 for left eyes. Ninety-nine (15.3%) of right eye measurements differed by 1 line, 7 (1.1%) differed by 2 lines, and 1 (0.2%) by 3 lines. One hundred nine (16.8%) of the left eye measurements differed by 1 line, 5 (0.8%) by 2 lines, and none by more than 2 lines.

Mean test–retest differences (the first measurement minus the second one) for cycloplegic retinoscopy were $+0.006\pm0.244$ D (standard deviation) for right eyes and -0.018 ± 0.256 D for left eyes. Neither of these differences was significantly different from zero (paired t test, $P = 0.560$ and $P = 0.069$). Reproducibility for cycloplegic autorefraction was comparable, with mean test–retest differences of $+0.003\pm0.237$ D for right eyes and -0.011 ± 0.237 D for left eyes ($P = 0.772$ and $P = 0.246$).

Results

Study Population

As the enumeration of eligible children proceeded, it became apparent that the required sample size would not be reached with the originally selected 25 clusters. Accordingly, an additional 10 clusters were randomly selected for inclusion in the study. A total of 35 clusters were, thus, enumerated between January and March 2003. One cluster was subsequently dropped from the study, because the government had moved most of the families to a new location.

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

Visual Acuity Category	Uncorrected Visual Acuity No. (%; 95% Confidence Interval)	Wearing Glasses No. (%)*	Presenting Visual Acuity No. (%; 95% Confidence Interval)	Best Visual Acuity No. (%; 95% Confidence Interval)
≥20/32 both eyes	3578 (77.4; 74.6–80.2)	32 (0.9)	3849 (83.3; 81.5–85.0)	4450 (96.3; 95.7–96.9)
≥20/32 one eye only	255 (5.52; 4.68–6.36)	21 (8.2)	307 (6.64; 5.53–7.75)	106 (2.29; 1.82–2.77)
≤20/40 to ≥20/63 better eye	446 (9.65; 8.44–10.9)	115 (25.8)	396 (8.57; 7.48–9.66)	62 (1.34; 0.98–1.70)
≤20/80 to ≥20/160 better eye	249 (5.39; 4.20–6.57)	185 (74.3)	66 (1.43; 1.05–1.81)	4 (0.09; 0.02–0.22)†
≤20/200 better eye	94 (2.03; 1.46–2.61)	90 (95.7)	4 (0.09; 0.02–0.22)†	0
All	4622 (100.0)	443 (9.6)	4622 (100.0)	4622 (100.0)

Cluster design effects, ranging from 0.928 to 0.962, are not reflected in the confidence intervals for exact binomial estimates. (Design effects ranging from 1.092 to 5.098 were taken into account in calculating confidence intervals for estimates based on the normal approximation.)
*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.

A total of 8541 households were identified. Interviews were possible in 8136 (95.3%) households, with 3004 (36.9%) of these having eligible children ages 7 to 15 years. A total of 5528 children were enumerated, ranging from 61 to 423 across the 34 study clusters. The age, gender, and ethnicity of enumerated children are shown in Table 1. Males constituted 51.4% of the total.

Compared with the Gombak district distribution, the percentage of Malays (70.0%) was greater and Chinese (16.6%) fewer. Ethnicity proportions were far from uniform across the 34 study clusters. Malays comprised more than 50% of the enumerated population in 25 clusters. In 4 clusters, Chinese ethnicity was 85% or greater. In 2 clusters, Indian ethnicity exceeded 30% of the population. In yet another cluster, more than 50% of the population was composed of "other" ethnicities.

Most of the eye examinations were conducted between March and July 2003 in 140 schools. The age, gender, and ethnicity distribution of the examined population (83.8% of those enumerated) is shown in Table 1. Examination rates exceeded 70% in all but 2 clusters.

Visual Acuity

Visual acuity findings are presented in Table 2. Measurements were not possible in 12 of the examined children. (Ten had delayed mental development and could not understand the testing process, and 2 were not cooperative.) Uncorrected visual acuity 20/32 or better in at least 1 eye was found in 3833 (82.9%) children. Seven hundred eighty-nine (17.1%) children had visual impairment in both eyes (≤20/40), with 94 (2.0%) of these blind (≤20/200) in both eyes. Uncorrected visual acuity was poorer in females (Kolmogorov–Smirnov test, $P<0.001$).

On the basis of enumeration interviews, 625 (13.5%) of the examined cohort wore glasses, with 115 wearing them only occasionally. At the examination, 443 (9.6%) children were wearing spectacles (Table 2). Among the 789 with visual impairment in both eyes based on uncorrected visual acuity, 390 (49.4%) were wearing spectacles. With their current refractive correction, 323 of these had normal/near-normal vision in at least 1 eye, leaving 466 children (10.1% of the total) with bilateral visual impairment, a 40.9% reduction over uncorrected vision. Four children remained bilaterally blind as measured by presenting vision.

By best-measured visual acuity, it was possible to further reduce bilateral visual impairment to 66 children (1.4% of the total), with none remaining bilaterally blind. Accordingly, a total of 723 (91.6%) of the 789 children with bilateral visual impairment could achieve normal/near-normal vision in at least 1 eye with refractive correction; 400 (50.7%) remained in need of refractive correction. Stated another way, 55.3% (400) of the 723 children who could achieve normal/near-normal vision in at least 1 eye were without the necessary correction.

Cycloplegic Refraction

Pupillary dilation and cycloplegia (dilation of at least 6 mm and the absence of light reflex) were achieved in 4580 (98.8%) right eyes and 4583 (98.9%) left eyes and in both eyes of 4576 (98.7%) children. Retinoscopy measurements were available for 4575 of the cycloplegic right eyes, 4579 of the left eyes, and both eyes of 4574 children. Autorefraction measurements were available for 4573, 4578, and 4572 children, respectively.

Refractive Error

Spherical equivalent refractive error varied with age, from a median of +0.875 D in 7-year-olds to +0.25 D in 15-year-olds, as

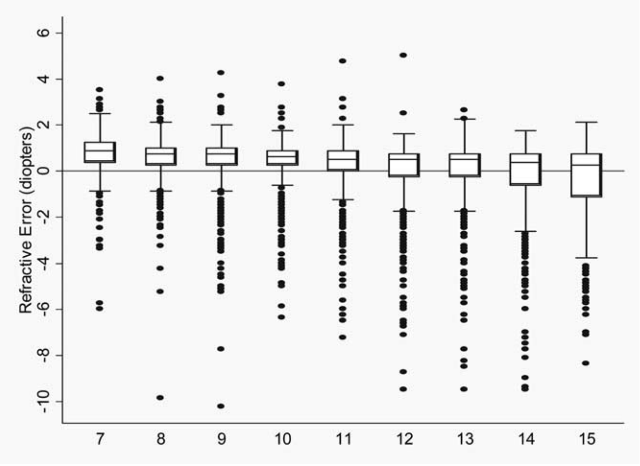

Figure 1. Distribution of spherical equivalent refractive error in right eyes by age (years) as measured with cycloplegic retinoscopy. Each box extends from the 25th to the 75th percentile of the age-specific distribution—the interquartile range—with the bar inside representing the median. Whiskers extend 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. Eight measurements (−16.75, −16.50, −14.875, −14.00, −11.75, −11.75, −10.375, and +6.625 diopters) are not shown.

Table 3. Prevalence of Ametropia (Either Eye) by Age, Gender, and Ethnicity with Cycloplegic Retinoscopy and Cycloplegic Autorefraction

	Hyperopia		Myopia	
	Retinoscopy %; 95% Confidence Interval	*Autorefraction %; 95% Confidence Interval*	*Retinoscopy %; 95% Confidence Interval*	*Autorefraction %; 95% Confidence Interval*
Age (yrs)*				
7	3.8; 2.4–5.2	5.0; 3.0–7.0	9.8; 6.7–12.9	10.0; 6.8–13.1
8	2.2; 0.9–3.4	2.0; 0.7–3.3	13.6; 10.3–16.9	14.0; 10.3–17.6
9	1.4; 0.3–2.5	1.6; 0.4–2.8	16.3; 11.5–21.2	16.3; 11.7–20.9
10	0.7; 0.1–1.4	1.4; 0.1–2.6	14.3; 10.3–18.2	16.2; 11.6–20.7
11	1.1; 0.3–1.9	0.9; 0.0–2.6	20.4; 14.7–26.2	22.6; 17.0–28.2
12	0.6; 0.0–1.2	0.6; 0.0–1.2	23.0; 17.5–28.7	24.8; 19.1–30.6
13	0.5; 0.0–1.1	0.5; 0.0–1.1	23.0; 17.4–28.5	25.3; 19.5–31.1
14	0.0;	0.0;	30.6; 24.2–37.1	32.5; 25.5–39.6
15	0.6; 0.0–1.5	0.9; 0.0–1.9	34.4; 28.6–40.2	32.5; 25.5–39.6
Gender†				
Male	1.2; 0.8–1.7	1.7; 1.1–2.3	17.5; 13.7–21.3	19.0; 15.2–22.7
Female	1.4; 0.8–1.9	1.4; 0.8–2.1	21.2; 17.8–24.6	22.5; 19.2–25.8
Ethnicity‡				
Malay	1.2; 0.9–1.6	1.5; 1.1–1.9	13.9; 12.0–15.8	15.4; 13.3–17.5
Chinese	0.9; 0.4–1.5	1.1; 0.4–1.7	45.3; 39.8–50.8	46.4; 40.9–51.9
Indian	1.7; 0.3–3.2	2.0; 0.1–3.9	15.5; 10.4–20.5	16.2; 11.1–21.3
Other	3.0; 1.2–4.9	4.1; 2.2–5.9	16.8; 13.4–20.1	18.2; 15.5–21.0
All§	1.3; 0.9–1.7	1.6; 1.1–2.1	19.3; 15.9–22.8	20.7; 17.3–24.1

*Cluster design effects ranged from 0.763 to 1.326 for hyperopia and from 1.286 to 2.410 for myopia.
†Cluster design effects ranged from 0.901 to 1.543 for hyperopia and from 3.378 to 5.682 for myopia.
‡Cluster design effects ranged from 0.418 to 1.850 for hyperopia and from 0.392 to 2.667 for myopia.
§Cluster design effects were 1.216 and 1.800 for hyperopia and 8.600 and 7.814 for myopia.

measured with cycloplegic retinoscopy in right eyes (Fig 1). With autorefraction, median refractive error ranged from +0.75 D in 7-year-olds to +0.25 D in 15-year-olds. Across all ages, spherical equivalent refractive error was less positive (more negative) in females with both retinoscopy and autorefraction (Kolmogorov–Smirnov test, $P = 0.002$ and $P<0.001$, respectively). The median spherical equivalent refractive error was +0.625 D in males and +0.50 D in females with either measurement method. Findings in left eyes were similar.

Ametropia by age, gender, and ethnicity is shown in Table 3. The prevalence of hyperopia decreased from 4% or 5% in 7-year-olds to less than 1% among 12-year-olds, before remaining at approximately 0.5% through age 15. Little difference in hyperopia prevalence was found between males and females or between ethnic groups. Myopia increased consistently with age, from approximately 10% in 7-year-olds to 33% or 34% in 15-year-olds. The prevalence of myopia in females was marginally higher than in males.

Myopia was more prevalent in children with Chinese ethnicity. With retinoscopy, myopia in Chinese increased steadily from 20.9% (95% confidence interval [CI], 13.3%–28.4%) in 7-year-olds to 65.4% (95% CI, 54.8%–75.9%) in 15-year-olds. In Malays, the increase went from 7.7% (95% CI, 4.6%–10.8%) in 7-year-olds to 30.7% (95% CI, 24.9%–36.4%) in 15-year-olds. In Indians, myopia prevalence ranged from 5.3% (95% CI, 1.1%–14.9%) in 7-year-olds to 16.1% (95% CI, 5.5%–33.7%) in 15-year-olds; after increasing to 16.7% in 8-year-olds, the prevalence remained essentially level, except for 25.6% in the 12-year-olds and 23.7% in 14-year-olds. (Data not shown.)

Multiple logistic regression was used to investigate the association of age, gender, parental education, and family ethnicity with myopia. Myopia (with either retinoscopy or autorefraction) was associated with older age, female gender, higher parental education, and Chinese ethnicity. Because of statistically significant pairwise interactions between model variables, particularly gender and ethnicity, separate models were constructed for each ethnic group. Modeling was also investigated separately for males and females.

Table 4 shows odds ratios with cycloplegic retinoscopy measurements for each of the 4 ethnic groups. The risk of myopia increased with increasing age at statistically significant levels, except among children of "other" ethnicity ($P = 0.832$). A higher risk of myopia was found among females in Malays and in the "other" ethnic group. For children with Chinese ethnicity, the risk in females was lower than in males, but not at a statistically significant

Table 4. Odds Ratios for Myopia within Ethnic Groups by Age, Gender, and Parental Education with Cycloplegic Retinscopy

	Malay	Chinese	Indian	Other
Age (yrs)	1.23* (1.17–1.28)	1.29* (1.19–1.38)	1.14 (0.99–1.30)	1.02 (0.80–1.32)
Female/male	1.39† (1.12–1.73)	0.84 (0.61–1.14)	0.90 (0.50–1.60)	4.05† (1.88–8.75)
Parental education (yrs)	1.09* (1.04–1.13)	1.10† (1.04–1.16)	1.09 (1.01–1.17)	1.07 (0.91–1.25)

Data are given as adjusted odds ratios (95% confidence interval).
*$P<0.001$.
†$P<0.010$.

Table 5. Odds Ratios for Myopia in Males and Females by Age, Parental Education, and Ethnic Subgroup with Cycloplegic Retinscopy

	Males	Females
Age (yrs)	1.18* (1.11–1.25)	1.28* (1.20–1.37)
Parental education (yrs)	1.10* (1.06–1.15)	1.08† (1.02–1.13)
Ethnicity		
Malay	—	—
Chinese	7.98* (5.63–11.31)	4.97* (3.60–6.87)
Indian	1.65† (1.03–2.67)	0.97 (0.53–1.76)
Other	0.70 (0.32–1.53)	2.03* (1.42–2.89)

Data are given as adjusted odds ratios (95% confidence interval).
*$P<0.001$.
†$P<0.010$.

level ($P = 0.240$). Among Malays, Chinese, and Indians, higher parental education was statistically significant, but not among those of "other" ethnicity ($P = 0.371$).

In segmenting the logistic regression based on gender, ethnicity was included as a covariate (Table 5). Compared with Malays, myopia risk was associated with Chinese ethnicity in both male and female models. Higher risk was also associated with Indian ethnicity among males and with "other" ethnicity among females. Older age and higher parental education were statistically significant in both male and female models.

In logistic regression modeling for hyperopia, it was possible to use a composite model with all covariates included. Child age was statistically significant (odds ratio [OR], 0.72; 95% CI, 0.62–0.82), reflecting the lower prevalence of hyperopia with increasing age. Children of "other" ethnicity were at significantly higher risk of hyperopia compared with Malays (OR, 3.72; 95% CI, 1.34–10.35). Hyperopia was not associated with gender or parental education.

Findings with cycloplegic autorefraction measurements were essentially equivalent to those with cycloplegic retinoscopy in both myopia and hyperopia modeling.

Astigmatism

Astigmatism of 0.75 D or greater was found in 12.2% of right eyes and in 12.4% of left eyes with retinoscopy and in 14.7% of right eyes and 15.3% of left eyes when measured with autorefraction (Table 6). The higher prevalence with autorefraction was because the autorefractor could pick up mild forms of astigmatism missed by retinoscopy. Astigmatism in either eye was present in 15.7% of children measured with retinoscopy and in 21.3% with autorefraction.

In multiple logistic regression modeling with age, gender, and ethnicity as covariates, astigmatism was associated with Chinese ethnicity with both retinoscopy (OR, 2.59; 95% CI, 2.04–3.28) and autorefraction (OR, 2.62; 95% CI, 2.07–3.32), and with Indian ethnicity with retinoscopy (OR, 1.39; 95% CI, 1.02–1.91) but not autorefraction ($P = 0.091$). The particularly high OR for Chinese ethnicity is consistent with the high prevalence of myopia in this cohort. Neither age nor gender was associated with astigmatism ($P = 0.161$ and $P = 0.735$, respectively, with retinoscopy; $P = 0.427$ and $P = 0.857$, respectively, with autorefraction).

Measurement Agreement

Agreement between cycloplegic retinoscopy and cycloplegic autorefraction was good, although spherical equivalent autorefraction readings were systematically more negative (less positive). The mean difference was -0.055 ± 0.282 D for right eye measurements and -0.031 ± 0.289 D for left eyes, both statistically significant (paired t tests, $P<0.001$). Systematic differences between retinoscopy and autorefraction were present across both negative and positive measurements.

Ocular Abnormalities

Tropia at near fixation was present in 31 (0.7%) children and in 34 (0.7%) with distance fixation. (One child could not be evaluated.) Tropia was mostly exotropia: 77% with near and 85% with distant fixation. With near fixation, 71.0% of tropia was 15° or less, 64.7% with distant fixation.

Exterior and anterior segment abnormalities were observed in 216 (4.7%) of the 4634 examined children. Eyelid abnormalities (ptosis, stye, chalazion) were observed in 36 eyes of 32 (0.7%) children. Conjunctival abnormalities, mainly the presence of papillae or follicles, were seen in 299 eyes of 168 (3.6%) children. Corneal abnormalities, mainly keratoconus, were present in 16 eyes of 12 (0.3%) children. Three children had right eye pupillary anomalies; 1 child had an enucleated eye because of retinoblastoma. Other anterior segment abnormalities were observed in 19 eyes of 14 (0.3%) children.

Media and fundus abnormalities were observed in 87 (1.9%) children. Lenticular opacities were present in 9 eyes of 6 (0.1%) children. Vitreous condensation was noted in 1 eye of 1 child. Fundus anomalies (mainly abnormal cup-to-disc ratios) were present in 146 eyes of 81 (1.7%) children.

Cause of Visual Impairment

Reduced vision was overwhelmingly associated with refractive error. For the 1044 children with uncorrected visual acuity 20/40 or worse in 1 or both eyes, 872 (83.5%) attained acuity 20/32 or better in both eyes with refractive correction (Table 2). Another 62 had correctable refractive error in 1 eye with an uncorrectable cause in the fellow eye, for a total of 934 (89.5%) children with refractive error as the cause of impairment in 1 or both eyes (Table 7).

Table 6. Prevalence of Astigmatism with Cycloplegic Retinscopy and Cycloplegic Autorefraction

Cylinder Value (Diopters)	Retinoscopy [n (%)]			Autorefraction [n (%)]		
	Right Eye	*Left Eye*	*Children**	*Right Eye*	*Left Eye*	*Children**
≤0.50	4015 (87.8)	4011 (87.6)	3858 (84.3)	3900 (85.3)	3876 (84.7)	3600 (78.7)
0.75–1.75	402 (8.8)	411 (9.0)	508 (11.1)	523 (11.4)	549 (12.0)	772 (16.9)
≥2.00	158 (3.4)	157 (3.4)	208 (4.6)	150 (3.3)	153 (3.3)	200 (4.4)
All	4575 (100.0)	4579 (100.0)	4574 (100.0)	4573 (100.0)	4578 (100.0)	4572 (100.0)

*Astigmatism data in children represent those with cycloplegic dilation in both eyes with categorization using the worse eye.

Table 7. Causes of Uncorrected Visual Acuity 20/40 or Worse

Cause	No. (%), Eyes with Uncorrected Visual Acuity 20/40 or Worse		No. (%), Children with Visual Acuity 20/40 or Worse (One or Both Eyes)*	Percent Prevalence in the Population (One or Both Eyes)*
	Right Eye	*Left Eye*		
Refractive error†	805 (86.5)	790 (87.6)	934 (89.5)	20.21
Amblyopia‡	19 (2.0)	17 (1.9)	30 (2.9)	0.65
Corneal opacity	1 (0.1)	0 (0.0)	1 (0.1)	0.02
Cataract	1 (0.1)	2 (0.2)	2 (0.2)	0.04
Retinal disorder	1 (0.1)	1 (0.1)	2 (0.2)	0.04
Other causes	3 (0.3)	2 (0.2)	4 (0.4)	0.09
Unexplained cause§	101 (10.8)	90 (10.0)	133 (12.7)	2.88
Any cause	931 (100.0)	902 (100.0)	1044 (100.0)	22.6

*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 1106 children across all specific causes exceeds the 1044 with "any cause" of impairment. Similarly, the total for the cause-specific prevalences exceeds the "any cause" prevalence. Prevalence calculations exclude the 12 examined children without visual acuity measurements.
†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 pathology was present.
‡Includes only cases meeting the defined tropia, anisometropia, or hyperopia criteria for amblyopia.
§Includes 93 right eyes and 82 left eyes of 121 children where the examining ophthalmologist concluded that amblyopia was the principal cause of impairment even though the amblyopia criteria were not met.

Amblyopia, satisfying explicit criteria,[6] was the cause of visual impairment in 30 (2.9%) children: 7 with a tropia; 19 with anisometropia 2.00 spherical equivalent diopters or more; 3 with tropia and anisometropia; and 1 with anisometropia and hyperopia $\geq$6.00 spherical equivalent diopters. Other causes of vision loss were uncommon. One hundred ninety-one eyes of 133 children had no explanation for reduced vision, including 175 eyes of 121 children in whom amblyopia was considered the cause, even though none of the explicit criteria was met.

Discussion

A total of 5528 children were enumerated and 4634 (83.8%) examined in this cross-sectional, population-based survey of school-age children in Gombak District. Age distributions of enumerated and examined children were nearly uniform until decreasing with the 13-year cohort and then decreasing further in 15 year olds. This drop-off in examined cases was the result of a smaller number of enumerated cases (older children might have moved away to study in residential schools elsewhere) and of lower examination response rates among older children who remained in the district.

Cluster design effects were unusually large for estimates dealing with the study population as a whole, as well as for gender-specific estimates. This was brought on by differences in the composition of ethnicity between clusters and the fact that (Chinese) ethnicity was a significant determinate of refractive error and visual impairment. Stated in general terms, because of homogeneity within clusters and heterogeneity between clusters, within-cluster variance was small compared with between-cluster variance.

Overall, the prevalence of uncorrected visual impairment 20/40 or worse in both eyes was 17.1%, which dropped to 10.1% with presenting vision, and reduced further to 1.4% with best-corrected visual acuity. The primary cause of visual impairment, myopia, was associated with Chinese ethnicity, older age, and higher parental education. Female gender was significant only among Malays and those of "other" ethnicity. Hyperopia was associated with younger age and "other" ethnicity.

Refractive error was also the dominant cause of visual impairment in the other RESC studies but with major differences in prevalence between them.[7–13] A direct relationship between myopia and community development is clearly apparent, with rural populations having a consistently lower prevalence of myopia than their more developed, urban counterparts. Myopia risk was lower in the semirural environment of Shunyi District[8] compared with urban Guangzhou,[13] and with Chinese in the urban Gombak District. Similarly, an increasing myopia risk was found in comparing first-grade children in a government school in the Xiamen countryside (in Southern China) with those in a private school in Xiamen city and with first-grade children of Chinese ethnicity in a centrally located school in Singapore.[16] The influence of community development is also evident in contrasting the lower prevalence of myopia in rural India,[10] with the somewhat higher prevalence in urban India,[11] and the even higher prevalence among Indians in Gombak District.

Comparisons across ethnic groups are also of interest. As reported here, and by contrasting findings from the 1987 and 1990 school-based studies in Kuala Lumpur,[3,4] it is apparent that Chinese children face a higher risk of myopia compared with Malays. Caution must be exercised, however, in attributing these ethnic differences in refractive error to a genetic component.[17] As evidenced by the substantial differences in refractive error that exist between populations of similar ethnicity, it is possible that lifestyle and other environmental factors, such as reading activity, are ultimately dominant in determining who has myopia.[18] Further research dealing specifically with the nature–nurture puzzle is needed.

This study provides information of public health significance regarding the unmet need for refractive correction.

Although correction of vision-impairing refractive error is easy, safe, and effective, more than half of the children (55%) who could achieve normal/near-normal vision in at least 1 eye were without the necessary spectacles. This unmet need for refractive correction was found in all RESC studies: 45% in Guangzhou, 72% in New Delhi, 73% in Shunyi District, 76% in La Florida, 83% in Durban, 92% in rural India, and 93% in rural Nepal.[7–13] As found in the Guangzhou study, barriers to spectacle use include factors such as parental unawareness of the vision problem, attitudes regarding the need for spectacles, high cost, and concern that wearing spectacles may cause progression of refractive error.[19]

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References

1. Holden BA, Resnikoff S. The role of optometry in Vision 2020. J Community Eye Health 2002;15:33–6.
2. Zainal M, Ismail SM, Ropilah AR, et al. Prevalence of blindness and low vision in Malaysian population: results from the National Eye Survey 1996. Br J Ophthalmol 2002;86:951–6.
3. Garner LF, Mohidin N, Chung KM, et al. Prevalence of visual disorders in Malaysia. Sains Malaysiana 1987;16:339–46.
4. Chung KM, Mohidin N, Yeow PT, et al. Prevalence of visual disorders in Chinese schoolchildren. Optom Vis Sci 1996;3: 695–700.
5. World Health Organization. Elimination of avoidable visual disability due to refractive errors. WHO/PBL/00.79. Available at: http://www.vzozo.org/Toolkit2/documents/WHO.PBL_00.79.pdf.
6. Negrel AD, Maul E, Pokharel GP, et al. Refractive Error Study in Children: sampling and measurement methods for a multi-country survey. Am J Ophthalmol 2000;129:421–6.
7. Pokharel GP, Negrel AD, Munoz SR, Ellwein LB. Refractive Error Study in Children: results from Mechi Zone, Nepal. Am J Ophthalmol 2000;129:436–44.
8. Zhao J, Pan X, Sui R, et al. Refractive Error Study in Children: results from Shunyi District, China. Am J Ophthalmol 2000; 129:427–35.
9. Maul E, Barroso S, Munoz SR, et al. Refractive Error Study in Children: results from La Florida, Chile. Am J Ophthalmol 2000;129:445–54.
10. Dandona R, Dandona L, Srinivas M, et al. Refractive error study in children in a rural population in India. Invest Ophthalmol Vis Sci 2002;43:615–22.
11. Murthy GV, Gupta SK, Ellwein L, et al. Refractive error in children in an urban population in New Delhi. Invest Ophthalmol Vis Sci 2002;43:623–31.
12. Naidoo KS, Raghunandan A, Mashige KP, et al. Refractive error and visual impairment in African children in South Africa. Invest Ophthalmol Vis Sci 2003;44:3764–70.
13. He M, Zeng J, Liu Y, et al. Refractive error and visual impairment in urban children in southern China. Invest Ophthalmol Vis Sci 2004;45:793–9.
14. Department of Statistics Malaysia. Preliminary Count Report. Population and Housing Census of Malaysia 2000. Kuala Lumpur: Department of Statistics Publications; 2001.
15. Stata Statistical Software [computer program]. Release 8.0. College Station, TX: Stata Corp.; 2003.
16. Zhan MZ, Saw SM, Hong RZ, et al. Refractive errors in Singapore and Xiamen, China—a comparative study in school children aged 6 to 7 years. Optom Vis Sci 2000;77: 302–8.
17. Mutti DO, Zadnik K, Adams AJ. Myopia: the nature versus nurture debate goes on. Invest Ophthalmol Vis Sci 1996;37: 952–7.
18. Saw SM, Chua WH, Hong CY, et al. Nearwork in early-onset myopia. Invest Ophthalmol Vis Sci 2002;43:332–9.
19. He M, Xu J, Yin Q, Ellwein LB. Need and challenges of refractive correction in urban Chinese school children. Optom Vis Sci. In press.