Refractive Error in Children in an Urban Population in New Delhi

G. V. S. Murthy,[1] Sanjeev K. Gupta,[1] Leon B. Ellwein,[2] Sergio R. Muñoz,[3] Gopal P. Pokharel,[4] Lalit Sanga,[1] and Damodar Bachani[5]

Purpose. To assess the prevalence of refractive error and related visual impairment in school-aged children in an urban population in New Delhi, India.

Methods. Random selection of geographically defined clusters was used to identify a sample of children 5 to 15 years of age. From December 2000 through March 2001, children in 22 selected clusters were enumerated through a door-to-door survey and examined at a local facility. The examination included visual acuity measurements, ocular motility evaluation, retinoscopy and autorefraction under cycloplegia, and examination of the anterior segment, media, and fundus. Myopia was defined as spherical equivalent refractive error of at least −0.50 D and hyperopia as +2.00 D or more. Children with reduced vision and a sample of those with normal vision underwent independent replicate examinations for quality assurance in four of the clusters.

Results. A total of 7008 children from 3426 households were enumerated, and 6447 (92.0%) examined. The prevalence of uncorrected, baseline (presenting), and best corrected visual acuity of 20/40 or worse in the better eye was 6.4%, 4.9%, and 0.81%, respectively. Refractive error was the cause in 81.7% of eyes with vision impairment, amblyopia in 4.4%, retinal disorders in 4.7%, other causes in 3.3%, and unexplained causes in the remaining 5.9%. There was an age-related shift in refractive error from hyperopia in young children (15.6% in 5-year-olds) toward myopia in older children (10.8% in 15-year-olds). Overall, hyperopia was present in 7.7% of children and myopia in 7.4%. Hyperopia was associated with female gender. Myopia was more common in children of fathers with higher levels of education.

Conclusions. Reduced vision because of uncorrected refractive error is a major public health problem in urban school-aged children in India. Cost-effective strategies are needed to eliminate this easily treated cause of vision impairment. (*Invest Ophthalmol Vis Sci.* 2002;43:623–631)

From the [1]Dr. Rajendra Prasad Centre for Ophthalmic Sciences, All India Institute for Medical Sciences, New Delhi, India; the [2]National Eye Institute, National Institutes of Health, Bethesda, Maryland; [3]Unidad de Epidemiologia Clinica, Universidad de La Frontera, Temuco, Chile; [4]Foundation Eye Care Himalaya, Kathmandu, Nepal; and the [5]National Programme for Control of Blindness, Ministry of Health, Government of India, New Delhi, India.

Supported by the regional office of the World Health Organization, New Delhi, India through the Ministry of Health and Family Welfare, Government of India.

Submitted for publication June 18, 2001; revised October 29, 2001; accepted November 6, 2001.

Commercial relationships policy: N.

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be marked "*advertisement*" in accordance with 18 U.S.C. §1734 solely to indicate this fact.

Corresponding author: Leon B. Ellwein, National Eye Institute, 31 Center Drive, Bethesda, MD 20892-2510; ellweinl@nei.nih.gov.

Refractive error is one of the most common causes of visual impairment around the world and the second leading cause of treatable blindness.[1] Using identical protocols, population-based refractive error surveys in children were recently conducted in China, Nepal, and Chile.[2–4] These Refractive Error Study in Children (RESC) surveys were designed to assess the age- and sex-specific prevalence of refractive error and related visual impairment in children of different ethnic origins and cultural settings, using consistent definitions and methods[5] and thereby providing directly comparable data from entirely different parts of the world. Limited population-based refractive error data are available from India,[6] with most obtained from convenience samples of school children.[7,8] These data are inadequate for planning cost-effective interventions—particularly in India, because of potentially significant biases brought about by underenrollment in postprimary schools of children from lower socioeconomic strata.[9]

The data on refractive error and related visual impairment reported in this article were obtained from urban school-aged children living in the large Trilokpuri segment of New Delhi in northern India. A companion survey was performed in a rural population near Hyderabad in south central India.[10] Both used the RESC protocol and examination methods.[5]

Trilokpuri, in the eastern part of the city, is one of nine administrative districts in New Delhi. New Delhi had a population of 9,420,644 in the 1991 census,[11] with an estimated population in 2001 of approximately 15 million. Trilokpuri consists of a socioeconomically heterogenous population: residing in low-income housing typical of urban resettlement colonies; in middle- and upper-middle income, multistoried apartment complexes; in urban slums within the area; and in several remaining original villages comprising lower-middle and middle economic strata. This population mix is typical of urban areas, with resettlement colonies found in the larger cities of India. Health services in Trilokpuri are provided by the government sector and by a large number of private practitioners (both licensed and self-styled). A few elite private schools and numerous public-funded, government-run schools are located in the area.

Methods

Sample Selection

Cluster sampling was used to identify the study population. Because the Trilokpuri segment of New Delhi was established only recently, the 1991 national census could not be used to adequately project the current population for use in defining clusters of approximately equal size. Accordingly, electoral rolls from the 1999 state assembly and national parliament elections were used. The number of registered voters in the Trilokpuri segment was 114,121. (Persons 18 years of age or older are required to register.) Using the 1991 age distribution for New Delhi as a whole, the Trilokpuri population was estimated as 196,760, with 44,861 children 5 to15 years of age.

Clusters were demarcated geographically using electoral college wards. Wards with large populations were subdivided, whereas wards with small populations were grouped, to produce an estimated 200 to 399 children 5 to15 years of age in each cluster. A total of 161 clusters were defined, and 22 were randomly selected for the study.

Sample size requirements were based on that originally calculated for the earlier RESC studies,[5] but with a 25% increase in the original sample size to accommodate lower examination response rates and larger cluster design effects.

Field Operations

The cooperation of local community leaders was solicited before the initiation of survey fieldwork, which was performed during a 3-month period beginning in mid-December 2000. During the first 4 weeks, eight enumerators working in pairs mapped the location of houses and conducted a house-to-house enumeration of children 5 to 15 years of age. The enumeration included those temporarily absent from the area for up to 6 months. Transient visitors and guests were excluded from the enumeration, as were children staying in hostels.

During the mapping, households were given a unique identification number, regardless of whether there was an eligible child in the house. (Vacant houses were also assigned an identification number.) If more than one family was living within the same premises but there were independent kitchens, each family was considered an independent household.

Eligible children were enumerated by name, age (completed years), and gender and given an identification slip for presentation at the examination site. Birth certificates and ration cards for the distribution of subsidized food and fuel were used as necessary in the verification of age and residency. Information on years of schooling completed and the name of the school was also recorded for each eligible child. Data on years of schooling of both parents were collected. Verbal informed consent was obtained from a responsible family member during the enumeration. Examination procedures were explained, including the blurring of vision due to cycloplegic eye drops. Children were asked to appear at the examination site with spectacles if they normally wore them.

Two examination stations were set up in a community health care facility. Children were accompanied to and from the examination site by enumerators or parents. No child was examined if he or she came without an escort. Children attending local schools were offered bus transportation to the examination site after school. (In public-funded schools in Delhi, girls attend school from 7 AM to noon, whereas boys attend in the afternoon from 1 to 6 PM) To increase examination participation, a rotating examination schedule was maintained within each cluster, under which, if the first round of examinations was scheduled on a weekday, the next round was scheduled on a weekend and vice versa. Examinations were generally offered between 9 AM and 7 PM. Children in clusters far from the hospital were examined in temporary examination sites set up in schools, community facilities, or apartment complex offices. The age of each child was verified before initiating the examination process, and those found ineligible were offered an examination, but were not included as study participants. Households refusing to participate in examinations were revisited at least two times in different weeks in an attempt to obtain cooperation. Near the end of the survey, children who failed to come to the clinical sites were offered an examination in their homes. Visual acuity was measured in daylight, and dilation and refraction were not performed.

Clinical Examination

Distance visual acuity testing, ocular motility evaluation, cycloplegic dilation, refraction, and a basic eye examination were performed by one of two clinical teams from the Dr. Rajendra Prasad Centre for Ophthalmic Sciences (R. P. Centre). An ophthalmologist and two ophthalmic technicians were on each team. The two ophthalmologists had 5 years of specialty experience, and the ophthalmic technicians had completed the minimum of a 2-year diploma course in optometry.

Visual acuity was measured at 4 m by an ophthalmic technician, using a retroilluminated log minimum angle of resolution (MAR) chart with five tumbling-E optotypes on each line (Precision Vision, La Salle, IL) and was recorded as the smallest line read with one or no errors. First, the right eye was tested and then the left eye, both without (uncorrected visual acuity) and with (presenting visual acuity) spectacles, if the child brought them. A lensometer was used in measuring lens power. Ocular motility was evaluated at both 0.5 and 4.0 m by an ophthalmic technician. Tropias were categorized as esotropia, exotropia, or vertical. The degree of tropia was measured using the corneal light reflex. Examination of the anterior segment (eyelid, conjunctiva, cornea, iris, and pupil) was performed by the team ophthalmologist with a magnifying loupe. Pupils were dilated with 2 drops of 1% cyclopentolate, administered 5 minutes apart. After 20 minutes, if a pupillary light reflex was still present, a third drop was administered. Light reflex and pupil dilation were evaluated after an additional 15 minutes. Cycloplegia was considered complete if the pupil dilated to 6 mm or greater and light reflex was absent. After cycloplegia, vision was refracted by an ophthalmic technician, regardless of visual acuity: first, using a streak retinoscope and then a handheld autorefractor (Retinomax K-Plus; Nikon Corp., Tokyo, Japan). The autorefractor was calibrated at the beginning of each working day. Subjective refraction was performed on children with uncorrected visual acuity of 20/40 or worse in either eye.

The eye examination was completed with slit lamp and direct ophthalmoscopic examination of the lens, vitreous, and fundus. Eyes with uncorrected visual acuity of 20/40 or worse were assigned a principal cause of impairment by the examining ophthalmologist, using a seven-item list (refractive error, amblyopia, corneal opacity due to trachoma, other corneal opacity, cataract, retinal disorder, and other causes). Refractive error was considered to be the cause of visual impairment in all eyes improving to 20/32 or better with refractive correction. Amblyopia was reported as the cause of impairment for eyes with best corrected visual acuity of 20/40 or worse and no apparent organic lesion, so long as one or more of the following criteria were met: (1) esotropia, exotropia, or vertical tropia at 4 m fixation or exotropia or vertical tropia at 0.5 m; (2) anisometropia of 2.00 spherical equivalent diopters or more; or (3) bilateral ametropia of at least +6.00 spherical equivalent diopters. Further details regarding examination methods are described in the original RESC methods article.[5]

Treatment of minor eye ailments and corrective spectacles were provided at the examination site free of charge. For additional follow-up and examination, children were referred to the R. P. Centre.

Survey fieldwork was preceded by 2 weeks of staff training, and a 5-day field exercise was performed in an urban area similar to the study area. A pilot study (full dress rehearsal) was performed in 2 nonstudy clusters in the Trilokpuri area early in December of 2000. The pilot study included evaluation of interobserver agreement among ophthalmic technicians.

Human subject research approval for the study protocol was obtained from the World Health Organization Secretariat Committee on Research Involving Human Subjects and the Institutional Review Board of the All India Institute of Medical Sciences. The research protocol adhered to the provisions of the Declaration of Helsinki for research involving human subjects.

Data Management and Analysis

Completed household enumeration and clinical examination forms were reviewed in the field for accuracy and missing values. Data entry and computerized verification were conducted at the R. P. Centre. Verification included checks on measurement data ranges, frequency distributions, and consistency among related measurements. Cleaned data sets were translated into system files for statistical analysis, conducted on computer.[12]

Prevalence of different levels of vision impairment and blindness (beginning with visual acuity of 20/40 or worse) was calculated for uncorrected acuity, baseline (presenting visual acuity at initial examination), and best measured visual acuity. The latter measurement was based on subjective refraction obtained in those with reduced uncorrected visual acuity.

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 myopic 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, with only children with cycloplegic dilation in both eyes included in refractive error analyses. The association of the child's age, gender, and years of schooling with myopia was explored with multiple logistic regression modeling. The father's level of schooling, categorized to correspond to distinct grade level achievement (none, 1–5 years, 6–12 years, 13–15 years, and >15 years), was included in the regression model as a surrogate for the socioeconomic status of the family. Pair-wise interactions between regression model variables were assessed simultaneously using a Wald F test[12] and were considered significant at $P <$ 0.10.

Confidence intervals for prevalence estimates and regression odds ratios were calculated with adjustment for clustering effects associated with the geographically defined cluster sampling design.[12] The magnitude of these effects was expressed by a ratio termed the design effect (deff), which is a comparison of the estimate of variance actually obtained with that that would have been obtained had simple random sampling been used. Lack of independence between measurements in right and left eyes of the same child was dealt with by not grouping right and left eyes in analyzing such data. Missing values were ignored in all analyses, and thus, their distribution was implicitly assumed to be similar to that of available data.

Quality Assurance

Quality assurance pertaining to visual acuity and refraction measurements over the course of the survey was monitored in four preselected study clusters. Measurements were repeated independently by a second ophthalmic technician in children with baseline visual acuity of 20/40 or worse in either eye and in approximately 10% of the remaining children.

Visual acuity in the 284 eyes of 142 quality-assurance subjects was distributed as follows: 0.35% had uncorrected visual acuity of 20/200 or worse, 8.1% had 20/160 to 20/80, 12.7% had 20/63 to 20/40, and 74.6% had 20/32 or better. Quality-assurance subjects were distributed across all ages, but only two were 5 years of age; four were 6 years of age. Reproducibility for both right-eye and left-eye visual acuity was good, with unweighted κ statistics of 0.81 and 0.80, respectively. Of the right eye measurements, 20 differed by 1 line, and none by more than 1 line. Twenty of the left-eye measurements differed by l line, and 1 by 3 lines. Mean test–retest differences between spherical equivalent values for cycloplegic retinoscopy were +0.028 ± 0.391 D) in right eyes and +0.046 ± 0.233 D in left eyes; the positive mean difference in left eyes was statistically significant (paired *t*-test, $P = 0.009$). The 95% upper and lower limits of agreement around the mean of the differences between the two values[13] were −0.739 to +0.795 D in right-eye measurements and −0.409 to +0.502 D in left eyes. Reproducibility of cycloplegic autorefraction was comparable, with mean test–retest differences of +0.025 ± 0.398 D in right eyes and +0.042 ± 0.209 D in left eyes; the positive difference in the left eye was also statistically significant ($P = 0.009$).

Results

Study Population

A total of 6668 households were identified within the 22 study clusters, with 3426 (51.4%) households having one or more eligible children. In households with eligible children, 36.4% had one such child, 35.1% had two, 18.6% had three, and 10.0% had four or more. Each of the nine largest households had six eligible children.

The number of enumerated children ranged from 202 to 452 per cluster, for a total of 7008 children (Table 1) with 3639 (51.9%) boys. Except for a relatively large number of 10-year-olds and a small number of 15-year-olds, the age-specific distribution was reasonably uniform. (The large number of 10-year-olds may have been the result of rounding age up for 9-year-olds and down for 11-year-olds.)

A total of 6527 (93.1%) eligible subjects appeared at the examination sites. However, in 80 children neither visual acuity measurement nor cycloplegic dilation was possible, leaving 6447 examined children (Table 1), including 287 children examined in the home. Examination response was 92.0% for both boys and girls and ranged from 83.5% to 97.9% across the 22 clusters. The age-sex distribution of the examined population was not significantly different from that of the enumerated population (χ^2 goodness of fit, $P = 0.719$).

Approximately three fourths of examined children were attending school, including almost all the younger ones but less than half of the 15-year-olds. Approximately 5% of children had never attended school. Twenty percent of fathers had no formal schooling; 12% had 1 to 5 years of schooling, 49% had 6 to 12 years, 13% had 13 to 15 years, and 7% had more than 15 years. Forty-eight percent of mothers had formal schooling, and 5% had more than 15 years of schooling.

Visual Acuity

Among examined children, 497 (7.7%) were not able to cooperate sufficiently for a proper visual acuity measurement; 423 were 5- or 6-year-olds. Overall, 5950 (84.9%) of the enumerated

Table 1. Age Distribution of Enumerated and Examined Children

Year of Age	Enumerated	Examined	Vision Measurement	Cycloplegic Dilation
5	642 (9.2)	552 (86.0)	241 (37.5)	512 (79.8)
6	598 (8.5)	556 (93.0)	422 (70.6)	494 (82.6)
7	639 (9.1)	590 (92.3)	563 (88.1)	544 (85.1)
8	690 (9.9)	639 (92.6)	621 (90.0)	582 (84.3)
9	626 (8.9)	599 (95.7)	597 (95.4)	544 (86.9)
10	718 (10.3)	670 (93.3)	668 (93.0)	590 (82.2)
11	634 (9.1)	598 (94.3)	598 (94.3)	528 (83.3)
12	675 (9.6)	636 (94.2)	634 (93.9)	560 (83.0)
13	636 (9.1)	593 (93.2)	593 (93.2)	510 (80.2)
14	609 (8.7)	543 (89.2)	542 (89.0)	451 (74.1)
15	541 (7.7)	471 (87.1)	471 (87.1)	381 (70.4)
All	7008 (100.0)	6447 (92.0)	5950 (84.9)	5696 (81.3)

Data are the number enumerated, with percentage of total in parentheses; number examined with percentage examined in parentheses; number with visual measurement with percentage measured in parentheses; and number with cycloplegic dilation with percentage dilated in parentheses.

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

Visual Acuity Category	Uncorrected Visual Acuity	Wearing Glasses	Baseline Visual Acuity	Best Corrected Visual Acuity
≥20/32 in both eyes	5416 (91.0; 88.7–93.3)	22 (0.41)	5508 (92.6; 91.3–93.9)	5828 (97.9; 97.4–98.5)
≥20/32 in one eye	153 (2.57; 2.00–3.14)	14 (9.2)	153 (2.57; 2.01–3.13)	74 (1.24; 0.89–1.60)
≤20/40 to ≥20/63 in the better eye	222 (3.73; 2.64–4.82)	42 (18.9)	208 (3.50; 2.62–4.37)	32 (0.54; 0.29–0.78)
≤20/80 to ≥20/160 in the better eye	113 (1.90; 1.25–2.54)	49 (43.4)	68 (1.14; 0.89–1.45)*	13 (0.22; 0.11–0.33)
≤20/200 in the better eye	46 (0.77; 0.26–1.28)	33 (71.7)	13 (0.22; 0.12–0.37)*	3 (0.05; 0.01–0.15)*
All	5950 (100.0)	160 (2.7)	5950 (100.0)	5950 (100.0)

Data for visual acuities are number examined, with percentage of total examined and 95% CI in parentheses. Data for wearing glasses are number examined, with percentage of those within each uncorrected visual acuity category in parentheses.

* Confidence intervals were calculated using the exact binomial distribution instead of the normal approximation. Cluster design effects ranging from 0.923 to 1.009 are not reflected in the confidence intervals for the three exact binomial estimates. Design effects ranging from 0.757 to 8.740 were taken into account in calculating confidence intervals for estimates based on the normal approximation.

children had visual acuity measurements, ranging from 37.5% in 5-year-olds to 95.4% in 9-year-olds.

Uncorrected visual acuity of 20/32 or better in at least one eye was found in 5569 (93.6%) children, corresponding to 381 (6.4%) having acuity of 20/40 or worse in both eyes (Table 2). Forty-six (0.77%) children had visual acuity of 20/200 or worse in the better eye, with 25 (0.42%) at less than 20/200, which is considered blindness according to the definition used in India. The distribution of uncorrected visual acuity did not differ between boys and girls (Kolmogorov-Smirnov test, $P = 0.570$).

One hundred sixty children (2.7%) were wearing glasses, 46 (28.9%) of these with baseline visual acuity of 20/40 or worse in at least one eye. Among the 381 children with uncorrected visual acuity of 20/40 or worse in the better eye, 124 (32.5%) were wearing glasses. Baseline visual acuity was 20/40 or worse in the better eye in 289 (4.9%) children, including 13 (0.22%) children with visual acuity of 20/200 or worse in the better eye, and 6 (0.10%) with blindness, with baseline visual acuity of less than 20/200.

Best corrected visual acuity measurement was available in 5950 children. Forty-eight (0.81%) children had best corrected visual acuity of 20/40 or worse in the better eye. Accordingly, 241 (4.1%) children were able to improve their baseline acuity to 20/32 or better in at least one eye with prescription glasses. Three (0.05%) children remained blind (<20/200) with best correction: one with anophthalmos, one with congenital hereditary endothelial dystrophy, and another with blindness of undetermined cause associated with hysteria and suspected malingering.

Pupillary Dilation

Cycloplegia in both eyes was achieved in 5696 (81.3%) of enumerated children —88.4% of examined children—including 64 children whose pupils did not dilate fully to 6 mm but in whom pupillary light reflex was absent. The percentage of enumerated children with cycloplegic dilation ranged from 70.4% in 15-year-olds to 86.9% in 9-year-olds (Table 1). Pupillary dilation was not obtained in some children, because they were examined at home, parents did not consent to dilation, or dilation was contraindicated for medical reasons. Parents with higher levels of education were particularly inclined to refuse papillary dilation of their children, even though they may have given permission for visual acuity measurements and the eye examination. Boys were more likely than girls to have pupils that would not dilate.

Refractive Error

Mean spherical equivalent refractive error in right eyes, as measured by cycloplegic retinoscopy, decreased with age (Fig. 1). Mean refractive error at all ages was +0.77 D in boys and +0.82 D in girls. Measurements were similar in the left eye (data not shown). As evidenced by the large SDs, refractive error varied considerably within each age cohort.

The distribution of refractive error was comparable across age cohorts (Fig. 2). Hyperopic measurements were slightly more prevalent among the young, whereas measurements of myopia were somewhat more prevalent among older children. Including all ages, hyperopia was found in 6.3% of right eyes and myopia in 6.7% (data not shown).

The prevalence of hyperopia and myopia by 1-year age intervals is shown in Table 3. In the study population as a whole, the prevalence of hyperopia was 7.7% (95% confidence interval [CI], 6.3%–9.2%; deff = 3.868) and the prevalence of myopia, 7.4% (95% CI, 5.0%–9.7%; deff = 10.487). With cycloplegic autorefraction, the overall prevalence of hyperopia was 7.4% (95% CI, 6.0%–8.8%; deff = 3.772) and of myopia 7.4% (95% CI, 5.2%–9.6%; deff = 9.250). The prevalence of only more severe forms of myopia (spherical equivalent refractive error of at least −2.00 D in one or both eyes measured by retinoscopy) was 1.8% (95% CI, 1.1%–2.4%; deff = 3.524). Hyperopia of +4.00 D or more in at least one eye was present in 1.2% (95% CI, 0.86%–1.6%; deff = 1.605).

Multiple logistic regression modeling was used to investigate the association of age, sex, child's years of schooling (as a continuous variable), and father's schooling (as a categorical variable) with myopia. Because of statistically significant interactions between model variables, it was necessary to fit separate models to children in different age cohorts: 5 to 7 years, 8 to 10 years, 11 to 13 years, and 14 to 15 years. Educational attainment of the father was associated with an increased risk of myopia in children aged 11 to 13 years (odds ratio [OR], 1.69; 95% CI, 1.29–2.23) and 14 to 15 years (OR, 1.49; 95% CI, 1.17–1.90). Figure 3 illustrates the increased prevalence of myopia among children of fathers with higher levels of schooling. The child's years of schooling and gender were not predictors of myopia in any of the age categories. With autorefraction, regression findings were similar, except that the father's schooling was significant earlier, beginning in the 8- to 10-year age group (OR, 1.48; 95% CI, 1.04–2.11), and the years of schooling of the child was marginally significant for the 14- to 15-year age group (OR, 1.17; 95% CI, 0.98–1.40).

In similar modeling for hyperopia, the child's years of schooling was inversely associated with hyperopia in both the 8- to 10-year (OR, 0.84; 95% CI, 0.70–1.00) and 11- to 13-year age group (OR, 0.89; 95% CI, 0.82–0.98) as measured by retinoscopy. Female gender was also associated with a higher risk in the 11- to 13-year age group (OR, 1.72; 95% CI, 1.05–2.81). The educational level of the father did not approach significance in any of the age categories. With autorefraction, the years of schooling of the child was significant in the 11- to

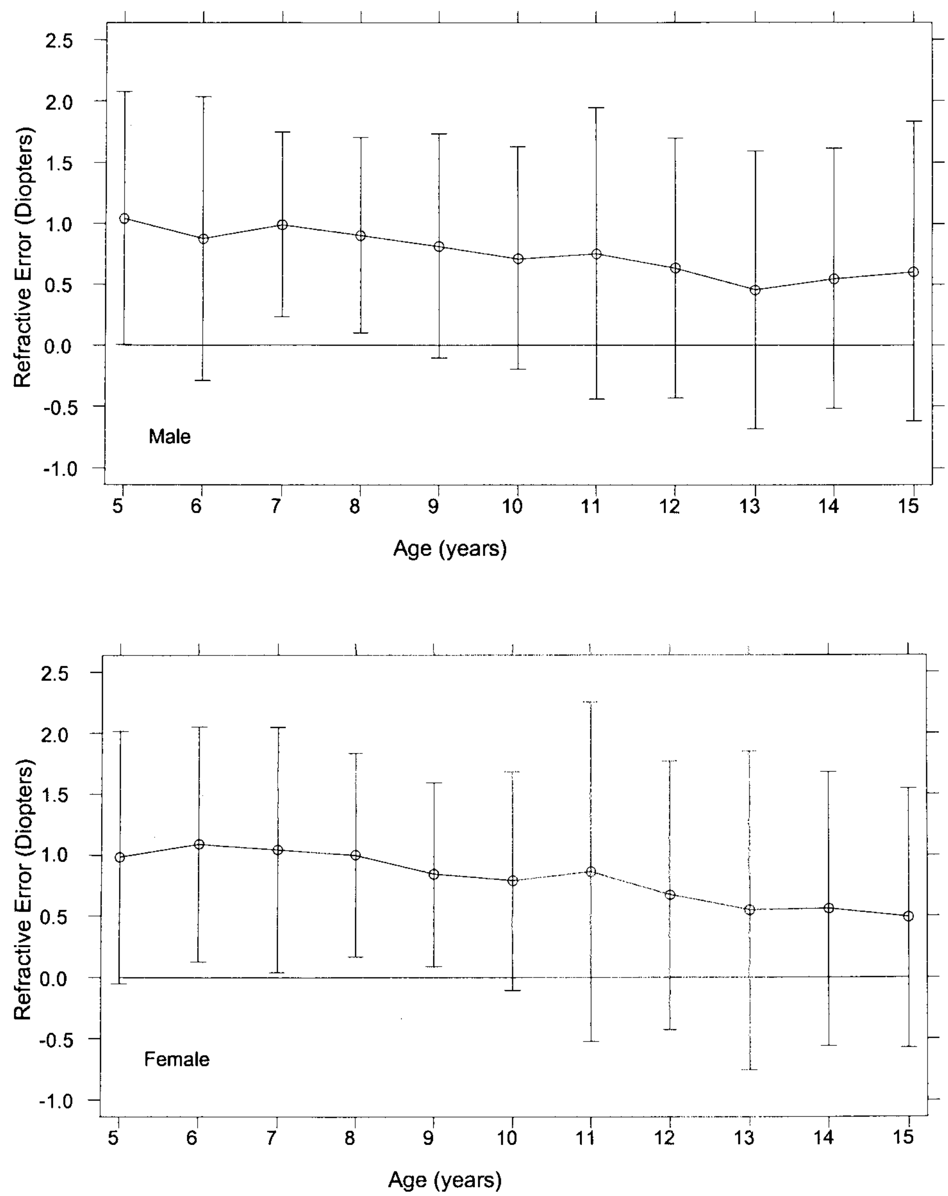

FIGURE 1. Mean right eye spherical equivalent refractive error by age in boys (*top*) and girls (*bottom*). *Vertical bars*: SDs.

13-year age group (OR, 0.89; 95% CI, 0.81–0.99), and marginally significant for children 8 to 10 years of age (OR, 0.86; 95% CI, 0.72–1.03).

In multiple logistic regression modeling for the more severe forms of myopia, the educational level of the father continued to be associated with increased risk in children 11 to 13 and 14 to 15 years of age. Severe myopia was also associated with the years of schooling of the child in those 8 to 10 and 11 to 13 years of age, and with female gender in those 14 to 15 years of age. None of the model variables was significant as predictors of the more severe form of hyperopia.

The educational attainment of the father was a determining factor in whether children with refractive error had corrective glasses. Among ametropic children with uncorrected visual acuity of 20/40 or worse in the better eye, 3.7% of children with fathers without schooling were wearing glasses, compared with 12.9% of children with fathers with 1 to 12 years of schooling, and 65.5% of those with fathers with 13 or more years of schooling.

Astigmatism of 0.75 D or greater was observed in 5.4% of both right and left eyes measured with retinoscopy and in 9.8% of right eyes and 10.2% of left eyes measured with autorefraction (Table 4). Higher prevalence was detected with autorefraction because of more mild astigmatism. Astigmatism in either eye was present in 7.0% of children measured with retinoscopy and in 14.6% measured with autorefraction. In multiple logistic regression, astigmatism in the right eye was associated with female gender with measurement by both retinoscopy and autorefraction ($P = 0.036$ and $P = 0.035$, respectively) and younger age ($P = 0.002$ and $P < 0.001$). In left eyes, astigmatism was associated with younger age with both measurement methods ($P = 0.060$ and $P = 0.001$) but not gender ($P = 0.535$ and $P = 0.178$). Astigmatism in the children was associated with younger age with both methods ($P = 0.005$ and $P = 0.001$) and female gender with autorefraction ($P = 0.025$). Age and gender were not predictors of astigmatism greater than 2.00 D with either measurement method.

In general, agreement between cycloplegic retinoscopy and cycloplegic autorefraction was good, with spherical equivalent autorefraction readings trivially more negative in right eyes (-0.010 ± 0.190 D), and more positive in left eyes ($+0.006 \pm 0.192$ D). The 95% CIs for agreement between the two measurement methods were -0.382 to $+0.361$ in right eyes and -0.369 to $+0.381$ in left eyes.

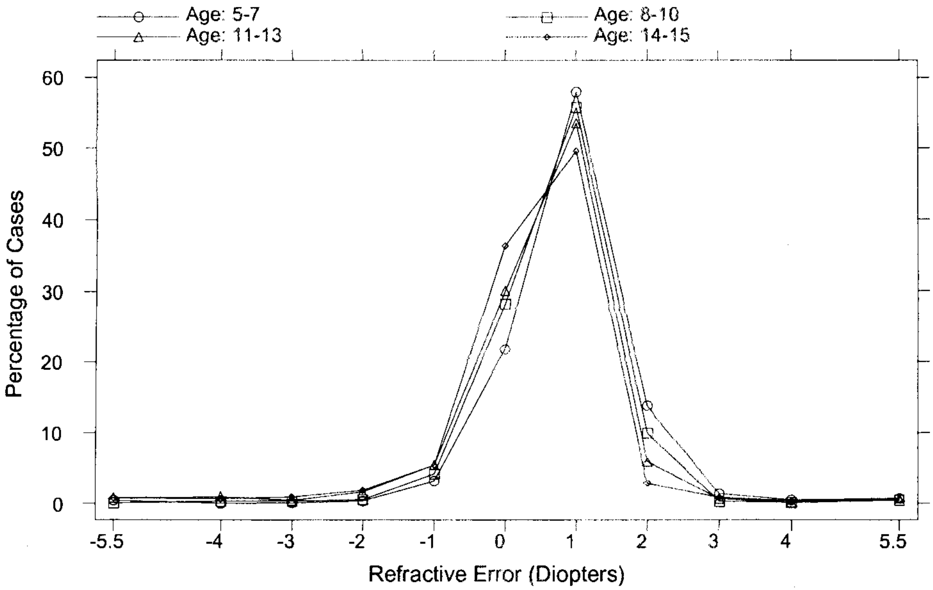

FIGURE 2. The distribution of spherical equivalent refractive error in right eyes. Data points represent a 1-D interval (for example, those associated with +1 on the *x*-axis represent greater than +0.50 D to +1.50 D or less). The two data points at the extreme ends represent −4.50 D or worse and greater than +4.50 D.

Other Ocular Abnormalities

Tropia was present in 34 (0.53%) of the children at distance and at near fixation. With both evaluations, 19 had esotropia, 14 had exotropia, and 1 had vertical tropia. Fifty-three percent of the tropias were 15° or less, whether measured with distance or near fixation.

Eyelid abnormalities (mainly blepharitis) were observed in 93 eyes of 65 (1.0%) children. Conjunctival abnormalities were present in 84 eyes of 47 (0.73%) children, including 46 eyes in 23 children with Bitot spots. Corneal abnormalities were observed in 27 eyes of 21 (0.33%) children, with opacities present in 18 children. Pupillary abnormalities were noted in 23 eyes of 19 (0.29%) children. Lenticular abnormalities were present in 17 eyes of 14 (0.21%) children. One child had bilateral subluxated lenses, 9 eyes of 9 children had aphakia or pseudophakia, and cataract was observed in 4 eyes of 3 children. Fundus abnormalities were seen in 70 eyes of 49 (1.2%) children (mainly macular degeneration). Three eyes of three children had retinal detachment, one eye with aphakia and silicone oil present. One child had a prosthetic eye and another anophthalmia.

Cause of Impairment

More than 80% of reduced visual acuity was because of refractive error (Table 5). Amblyopia satisfying the predefined criteria was the cause of uncorrectable vision impairment in another 34 (6.4%) children: 6 had tropia, 27 had anisometropia, and 3 had bilateral hyperopia. In another 48 eyes of 33 children, the criteria were not met, but amblyopia was considered the most likely cause by the examining ophthalmologist. These cases are included among those with unexplained causes in Table 5. Retinal disorders (including macular degeneration, retinal degeneration, macular scar, myopic fundus, and coloboma) were the other significant causes affecting 5.1% of children with vision impairment.

Discussion

A total of 7008 children were enumerated in this cross-sectional, population-based survey of urban school-aged children in a segment of New Delhi, India. Except for a higher proportion of 10- and 14-year-old girls, the enumerated population was generally comparable with the age and gender distribution in the 1991 census for Delhi as a whole.[9] Ninety-two percent of enumerated children were examined. Sometimes five or more second household visits were necessary before participation was obtained, particularly in clusters of relatively high socioeconomic status. Participation in examinations among older male children was also affected by employment, whereas among girls parental worry about security was an issue in clusters with a history of law-and-order problems.

TABLE 3. Prevalence of Ametropia by Age with Cycloplegic Retinoscopy

Age (y)	Myopia* (%; 95% CI)	Hyperopia† (%; 95% CI)
5	4.68; 2.54–6.83	15.6; 11.0–20.2
6	5.87; 2.59–9.15	13.0; 9.12–16.8
7	3.13; 1.17–5.08	10.7; 7.09–14.2
8	5.67; 2.50–8.84	8.59; 5.95–11.2
9	5.33; 2.61–8.05	6.62; 3.71–9.52
10	6.95; 3.44–10.5	5.25; 2.38–8.13
11	9.85; 5.91–13.8	7.77; 4.71–10.8
12	9.66; 5.64–13.7	5.01; 3.52–6.50
13	10.6; 6.02–15.2	3.33; 1.70–4.96
14	10.2; 6.85–13.5	4.43; 2.41–6.46
15	10.8; 6.71–14.8	3.94; 2.14–5.74

* Cluster design effects ranged from 1.216 to 2.604.
† Cluster design effects ranged from 0.605 to 2.259.

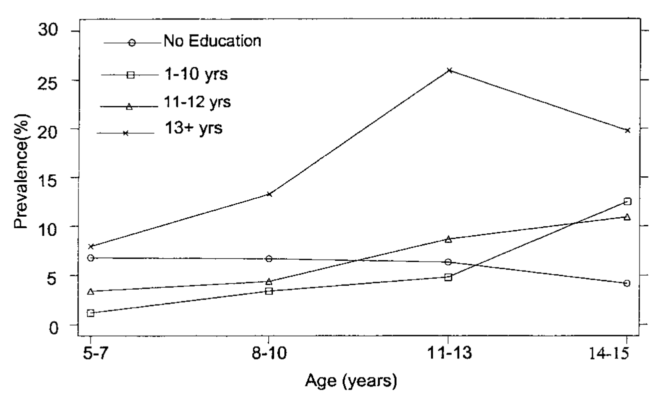

FIGURE 3. Prevalence of myopia by age and the father's level of education.

TABLE 4. Prevalence of Astigmatism with Cycloplegic Retinoscopy and Cycloplegic Autorefraction

Astigmatism (D)	Retinoscopy			Autorefraction		
	Right Eye	Left Eye	Children*	Right Eye	Left Eye	Children*
<0.75	5382 (94.6)	5386 (94.6)	5295 (93.0)	5132 (90.2)	5110 (89.8)	4863 (85.4)
≥0.75 to <2.00	238 (4.2)	232 (4.1)	300 (5.3)	483 (8.5)	501 (8.8)	719 (12.6)
≥2.00	71 (1.2)	75 (1.3)	100 (1.7)	74 (1.3)	79 (1.4)	112 (2.0)
All	5691 (100.0)	5693 (100.0)	5595 (100.0)	5689 (100.0)	5690 (100.0)	5694 (100.0)

Data are number of eyes or children examined, with percentage of the total examined in parentheses.
* Degree of astigmatism in persons categorized using the worse eye.

Visual acuity measurements were available for only 37.5% and 70.6% of 5- and 6-year-old children, respectively. This is in contrast to the availability of such measurements for 91.7% (5287/5765) of enumerated children aged 7 to 15 years. Although there was difficulty in testing 5- and 6-year-olds, when obtainable, visual acuity measurements were shown to be generally reliable. Rarely did test–retest measurements differ by more than one line. Consideration was given to excluding 5- and 6-year-olds in reporting study findings, but they were retained, because cycloplegic refraction was usually possible. Nonparticipation in cycloplegic dilation was most pronounced among older children.

Overall, cycloplegic refraction data were not available in 11.7% of examined children, but were available in 16.9% of 14-year-olds and 19.6% of 15-year-olds. In 14- and 15-year-old children with fathers with more than 15 years of schooling, nonparticipation exceeded 60%. Educated parents frequently considered the prospect of their child's missing out on tutorials and study time because of blurred vision unacceptable, despite repeated attempts to convince them of the importance of cycloplegic refraction in achieving study objectives. Conducting the survey later in the year, during the school vacation period, would have mitigated much of the resistance to cycloplegia. However, absenteeism of well-to-do families from the area for 1 to 2 months would then have been a problem. Because of the differentially low participation in cycloplegic dilation and refraction among those of highest risk—namely, older children and children of parents with high levels of schooling—we may have underestimated the prevalence of myopia in older children. Hyperopia was found primarily in younger children, and thus, this problem with nonparticipation in papillary dilation should not have had nearly the same effect on the estimation of hyperopia prevalence.

Test–retest reproducibility of retinoscopy and autorefraction readings was good. In both methods, repeat measurements of right eyes were within 0.75 D 95% of the time, and within 0.50 D in left-eye measurements. Although the repeat measurement of left eyes had a tendency to be less positive than the first measurement—with both methods—the magnitude of this systematic difference was inconsequential, as reflected in mean differences that were near zero. Agreement between retinoscopy and autorefraction was also good, with 95% of measurements differing by less than 0.50 D and with no systematic differences between measurements in either right or left eyes.

The prevalence of hyperopia (7.7%) was between the 3.5% and 16.3% reported in China[2] and Chile,[4] respectively, and more than the 1.4% found in rural Nepal[3] and the 0.8% in rural India.[10] A higher prevalence of hyperopia was observed in girls, which was statistically significant in the 11- to 13-year age group. The association between female gender and hyperopia was also found in China, Nepal, and Chile. In New Delhi children, the emmetropization process appeared to be associated with the child's years of schooling, independent of the influence of age.

The prevalence of myopia (7.4%) was comparable with the 6.8% in Chile,[4] substantially lower than the 16.2% in China,[2] and more than the 1.2% in Nepal[3] or the 4.1% in rural India.[10] Fathers with higher levels of education were more likely to have children with myopia—a finding that was also true in rural India, even though there were relatively few families of high educational status. (Information on the schooling of par-

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

Cause	Eyes with Uncorrected Visual Acuity 20/40 or Worse		Children with Visual Acuity 20/40 or Worse (One or Both Eyes)	Percentage Prevalence in Population (One or Both Eyes)*
	Right Eye	Left Eye		
Refractive error†	369 (82.7)	379 (80.8)	432 (80.9)	7.26
Amblyopia‡	16 (3.6)	24 (5.1)	34 (6.4)	0.57
Corneal opacity	4 (0.90)	4 (0.85)	7 (1.3)	0.12
Cataract	0 (0.0)	2 (0.43)	2 (0.37)	0.03
Retinal disorder	20 (4.5)	23 (4.9)	27 (5.1)	0.45
Other causes	10 (2.2)	10 (2.1)	13 (2.4)	0.22
Unexplained cause§	27 (6.1)	27 (5.8)	38 (7.1)	0.64
Any cause	446 (100.0)	469 (100.0)	534 (100.0)	8.97

Data are number of eyes or children examined, with percentage of total examined in parentheses.
* Children with visual acuity of 20/40 or worse in both eyes may represent a different cause of reduced vision in the two eyes; thus, the total for all causes exceeds the any-cause percentage.
† Refractive error was assigned as the cause of reduced vision in eyes correcting to 20/32 or better with subjective refraction.
‡ Includes only cases meeting defined tropia, anisometropia, or hyperopia criteria for the presence of amblyopia.
§ Includes 48 eyes of 33 children in whom the examining ophthalmologist concluded that amblyopia was the probable cause of impairment, but the amblyopia criteria were not met.

ents was not collected in the Nepal, China, or Chile surveys.) Except for the higher prevalence of the more severe forms of myopia in girls 14 to 15 years of age, myopia was not associated with gender. Myopia of any severity was associated with female gender in rural India and China.

The 5.4% prevalence of astigmatism was more than the 2.2% and 2.8% found in Nepal[3] and rural India,[10] but substantially less than the 15% in China[2] or the 19% in Chile.[4] The pattern of astigmatism generally followed that observed for refractive error in general. Except for China, astigmatism was more prevalent when measured with cycloplegic autorefraction.

To the extent that the educational attainment of the father is a surrogate indicator of family socioeconomic status and the emphasis that may be given to the schooling of children, the association of the father's education with myopia in children is consistent with the hypothesis that myopia is fostered by reading and other close work.[14,15] Comparatively low rates of myopia were found in both rural Nepal and rural India—underdeveloped areas where children are not faced with the same emphasis on schooling and frequently withdraw from school at an early age—which is also consistent with the schooling-intensity hypothesis. The study population in the Chile survey, which was conducted in a suburban area of the capital city of Santiago, is likely to be comparable with the urban New Delhi population in terms of the educational environment, as it was in its similarity with myopia prevalence. Schooling intensity may have been particularly operative in the China population, where emmetropization and the subsequent development of myopia appear to have taken place at a particularly early age. Although the China survey area outside Beijing City is considered rural, schooling is recognized as being intense in this area. (Children from Beijing City attend boarding schools in the survey area.) Any attribution of myopia to schooling intensity must be made with caution, however, because it is not possible to separate such environmental influences on myopia from those with a genetic basis. Indeed, if parents with higher levels of education generally had myopia, the observed association could be primarily one of genetic origin.[16,17] Data on the refractive error status of parents was not collected in any of the five RESC surveys.

Clustering of refractive error associated with environmental and/or genetic influences within families[18] or within the larger geographically defined cluster (i.e., neighborhood) is embedded in the study findings. The unusually large design effect of 10.487 that accompanied the estimation of myopia's prevalence in the study population as a whole, is an indication that clustering effects were sometimes substantial, and when they were, they had a detrimental effect on the statistical power of the survey, as demonstrated by the wide confidence interval accompanying the myopia estimate. Large cluster effects come about when there is a high degree of homogeneity within clusters and heterogeneity between clusters for the variable being estimated. Clustering effects to the same extent were not seen in the estimation of hyperopia's prevalence.

Clustering of refractive error at the neighborhood level, such as might be associated with the socioeconomic status of the community and the related emphasis placed on schooling, may have had a much greater influence than that at the family level. Indeed, when the influence of multiple children from the same family was removed in the estimation of myopia, by basing it on only one child from each family, the oldest, clustering effects remained substantial (deff = 6.659). This suggests that familial clustering, although it influences the original estimate of myopia, appears to be overshadowed by community-level influences that are outside the family structure. (A detailed investigation of the sources and effects of refractive-error clustering was beyond the scope of this study.)

Although worldwide geographic and ethnic differences in the prevalence of childhood refractive error are well recognized,[19–28] meaningful comparisons between reports in the literature are problematic. The difficulty arises because of different or inadequately described survey and examination methods (such as whether cycloplegia was used), unclear or nonuniform definitions for hyperopia and myopia, and differences underlying the age and gender mix of the populations studied.[27] Accordingly, we have limited our comparisons to the five studies in which the RESC protocol was used.

Blindness was not a major problem in the study population, with 0.1% of children with baseline (presenting) visual acuity of less than 20/200 in the better eye; however, visual impairment was substantial. Baseline visual acuity of 20/40 or worse in the better eye was found in 4.9% of the study population and in 0.81% with best correction. With uncorrected visual acuity, the percentage was 6.4%. This compares with 2.6%, 0.78%, and 2.7%, respectively, in the survey in rural India.[10] Refractive error in urban children accounts almost completely for this difference in vision impairment between urban and rural populations. Differences, although small, were also present in the prevalence of vision-impairing amblyopia and corneal opacities. Amblyopia and corneal opacity, which can be an amblyopiogenic factor, were more prevalent in rural children, with prevalences of 0.78% and 0.32%, respectively, compared with 0.57% and 0.12% in urban children.

The magnitude of the difference between baseline and best corrected visual acuity in the New Delhi survey indicates that more than an 80% reduction in bilateral vision impairment could be realized if all children were provided with appropriate spectacles. An unmet need for spectacles was also found in rural India[10] and in the other RESC surveys, particularly in China[2] and Chile.[4] Because such a large percentage of children with vision-reducing refractive error are apparently not wearing eyeglasses, population-based screening programs may be necessary to reduce visual impairment among school-aged children. Substantial benefit could be realized by the provision of refraction services and the availability of affordable spectacles. Although children from families in which the father had relatively high educational attainment were much more likely than others to have glasses, approximately one third did not. Accordingly, vision screening should not necessarily exclude children from relatively high socioeconomic areas, where the necessity to provide spectacles free of charge is likely to be minimal. Although current practice in the School Eye Screening Program in India is to begin screening at 12 to 14 years of age, data from this and the other RESC surveys suggest that screening for myopia might begin earlier, perhaps at approximately 11 to 12 years of age when the prevalence of myopia appears to increase markedly.

Acknowledgments

The authors thank Neena John, R. P. Centre, for her efforts in data management, and Tara Dutt Pant, R. P. Centre, for his untiring efforts in fieldwork and data collection.

References

1. Dandona R, Dandona L. Refractive error blindness. *Bull World Health Organ.* 2001;79:237–243.
2. Zhao J, Pan X, Sui R, Munoz SR, Sperduto RD, Ellwein LB. Refractive error study in children: results from Shunyi District, China. *Am J Ophthalmol.* 2000;129:427–435.
3. Pokharel GP, Negrel AD, Munoz SR, Ellwein LB. Refractive error study in children: results from Mechi Zone, Nepal. *Am J Ophthalmol.* 2000;129:436–444.
4. Maul E, Barroso, Munoz SR, Sperduto R, Ellwein LB. Refractive Error study in children: results from La Florida County, Chile. *Am J Ophthalmol.* 2000;129:445–454.

5. Negrel AD, Maul E, Pokharel GP, Zhao J, Ellwein LB. Refractive error study in children: sampling and measurement methods for a multi-country survey. *Am J Ophthalmol.* 2000;129:421–426.
6. Dandona R, Dandona L, Naduvilath TJ, et al. Refractive errors in an urban population in southern India: The Andhra Pradesh Eye Disease Study. *Invest Ophthalmol Vis Sci.* 1999;40:2810–2818.
7. Limburg H, Vaidyanathan K, Dalal HP. Cost effective screening of school children for refractive errors. *World Health Forum.* 1995;16:173–178.
8. Kalikivayi V, Naduvilath TJ, Bansal Ak, Dandona L. Visual impairment in school children in southern India. *Indian J Ophthalmol.* 1997;45:129–134.
9. Registrar General and Census Commissioner, India. *Census of India 1991, Series 1. India: Socio-Cultural Tables*. Vol. 2. New Delhi: Government of India, 1997.
10. Dandona R, Dandona L, Srinivas M, et al. Refractive error in children in a rural population in India. *Invest Ophthalmol Vis Sci.* 2002;43:615–622.
11. Registrar General and Census Commissioner, India. *Census of India 1991*. New Delhi: Ministry of Home Affairs, Government of India; 1992.
12. StataCorp. *Stata Statistical Software: Release 7.0*. College Station, TX: Stata Corp.; 2001.
13. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet.* 1986: 1(8476):307–310.
14. Angle J, Wissmann DA. The epidemiology of myopia. *Am J Epidemiol.* 1980;111:220–228.
15. Hung GK, Ciuffreda KJ. The effect of nearwork on transient and permanent myopia [ARVO Abstract]. *Invest Ophthalmol Vis Sci.* 2001;42(4):S392 Abstract nr 2117.
16. Mutti DO, Zadnik K, Adams AJ. Myopia: the nature versus nurture debate goes on. *Invest Ophthalmol Vis Sci.* 1996;37:952–957.
17. Zadnik K, Mutti DO, Mitchell GL, Jones LA, Moeschberger ML. The association between parental myopia, near work, and children's refractive error [ARVO Abstract]. *Invest Ophthalmol Vis Sci.* 2001; 42(4):S301. Abstract nr 1622.
18. The Framingham Offspring Eye Study Group. Familial aggregation and prevalence of myopia in the Framingham offspring eye study. *Arch Ophthalmol.* 1996;114:326–332.
19. Fledelius HC. Myopia prevalence in Scandinavia. *Acta Ophthalmol.* 1988;185(suppl):44–50.
20. Garner LF, Meng CK, Grosvenor TP, Mohiden N. Ocular dimensions and refractive power in Malay and Melanesian children. *Ophthalmic Physiol Opt.* 1990;10:234–238.
21. Turacli ME, Aktan SG, Duruk K. Ophthalmic screening of school children in Ankara. *Eur J Ophthalmol.* 1995;5:181–186.
22. Lithander J. Prevalence of myopia in school children in the Sultanate of Oman: a nation-wide study of 6292 randomly selected children. *Acta Ophthalmol Scand.* 1999;77:306–309.
23. Garner LF, Owens H, Kinnear RF, Frith MJ. Prevalence of myopia in Sherpa and Tibetan children in Nepal. *Optom Vis Sci.* 1999;76: 282–285.
24. Edwards MH. The development of myopia in Hong Kong children between the ages of 7 and 12 years: a five-year longitudinal study. *Ophthalmic Physiol Opt.* 1999;19:286–294.
25. Lin LK, Shih YF, Tsai CB, et al. Epidemiologic study of ocular refraction among schoolchildren in Taiwan in 1995. *Optom Vis Sci*. 1999;76:275–281.
26. Matsumura H, Hirai H. Prevalence of myopia and refractive changes in students from 3 to 17 years of age. *Surv Ophthalmol.* 1999;44(suppl.):S109–S115.
27. Saw SM, Katz J, Schein OD, Chew SJ, Chan TK. Epidemiology of myopia. *Epidemiol Rev.* 1996;18:175–187.
28. World Health Organization. *Elimination of Avoidable Visual Disability Due to Refractive Errors.* Geneva: World Health Organization; 2000. WHO/PBL/00.79.