

# Refractive Error in Children in a Rural Population in India

Rakhi Dandona,<sup>1,2</sup> Lalit Dandona,<sup>1,2</sup> Marmamula Srinivas,<sup>1</sup> Prashant Sabare,<sup>1</sup> Saggam Narsaiab,<sup>1</sup> Sergio R. Muñoz,<sup>3</sup> Gopal P. Pokharel,<sup>4</sup> and Leon B. Ellwein<sup>5</sup>

**PURPOSE.** To assess the prevalence of refractive error and related visual impairment in school-aged children in the rural population of the Mahabubnagar district in the southern Indian state of Andhra Pradesh.

**METHODS.** Random selection of village-based clusters was used to identify a sample of children 7 to 15 years of age. From April 2000 through February 2001, children in the 25 selected clusters were enumerated in a door-to-door survey and examined at a rural eye center in the district. The examination included visual acuity measurements, ocular motility evaluation, retinoscopy and autorefractometry 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 seven clusters.

**RESULTS.** A total of 4414 children from 4876 households was enumerated, and 4074 (92.3%) were examined. The prevalence of uncorrected, baseline (presenting), and best corrected visual acuity of 20/40 or worse in the better eye was 2.7%, 2.6%, and 0.78%, respectively. Refractive error was the cause in 61% of eyes with vision impairment, amblyopia in 12%, other causes in 15%, and unexplained causes in the remaining 13%. A gradual shift toward less-positive values of refractive error occurred with increasing age in both boys and girls. Myopia in one or both eyes was present in 4.1% of the children. Myopia risk was associated with female gender and having a father with a higher level of schooling. Higher risk of myopia in children of older age was of borderline statistical significance ( $P = 0.069$ ). Hyperopia in at least one eye was present in 0.8% of children, with no significant predictors.

**CONCLUSIONS.** Refractive error was the main cause of visual impairment in children aged between 7 and 15 years in rural India. There was a benefit of spectacles in 70% of those who had visual acuity of 20/40 or worse in the better eye at baseline examination. Because visual impairment can have a significant impact on a child's life in terms of education and development,

it is important that effective strategies be developed to eliminate this easily treated cause of visual impairment. (*Invest Ophthalmol Vis Sci.* 2002;43:615-622)

Refractive error is one of the most common causes of visual impairment around the world and the second leading cause of treatable blindness.<sup>1</sup> Reliable data on prevalence and distribution of refractive error from population-based surveys are needed to plan cost-effective programs for reduction of visual impairment and blindness. Few population-based data on refractive error are available from India,<sup>2</sup> but some are available for children attending school.<sup>3</sup> Data obtained only from children going to school cannot be reliably used to plan eye-care services, however, because they are not representative of the population at large, particularly in India, where a significant proportion of school-aged children do not attend school.<sup>4</sup>

To address a widespread need for population-based data on childhood refractive error, a Refractive Error Study in Children (RESC) protocol was prepared to assess the prevalence of refractive error and related visual impairment in children of different ethnic origins and cultural settings, by using consistent definitions and methods.<sup>5</sup> RESC surveys were recently conducted in China, Nepal, and Chile, and results have been published.<sup>6-8</sup> This article reports on an RESC survey conducted in school-age children in a rural area of the Mahabubnagar district, in the southern Indian state of Andhra Pradesh. A companion article in this issue reports RESC data from an urban population residing in metropolitan New Delhi.<sup>9</sup> A significant difference between this survey, the earlier ones, and the companion study in New Delhi is that the sample was drawn from children between 7 and 15 years of age, rather than 5 and 15 years.

## METHODS

### Sample Selection

The Mahabubnagar district was chosen for this survey, because the L. V. Prasad Eye Institute has recently established a rural eye center in the district, which was important in facilitating study logistics. The population of the Mahabubnagar district was estimated at 3 million in 1991,<sup>10</sup> with an estimated 3.5 million in 2000, predicated on an annual growth rate of 1.8%. The Mahabubnagar district has 64 mandals (administrative units) of which five mandals with villages within a 50-km radius of the rural eye center were chosen for the study. The mandals selected and their estimated population in 2000 were: Bijanapally (66,400), Gopalpet (55,700), Nagarkurnool (44,000), Tadoor (37,900), and Telkapalle (47,900). This district is one of the poorest districts in Andhra Pradesh. Agriculture is the main occupation for most persons in this district.

Cluster sampling was used to select a random sample of eligible children. Villages with an estimated population of less than 700 were combined with other small village(s), whereas those with populations of more than 1450 were subdivided, to create 248 clusters. Each cluster had an estimated population between 743 and 1415 (mean

From the <sup>1</sup>International Centre for Advancement of Rural Eye Care, L. V. Prasad Eye Institute, Hyderabad, India; the <sup>2</sup>Centre for Social Services, Administrative Staff College of India, Hyderabad, India; <sup>3</sup>Unidad de Epidemiología Clínica, Universidad de la Frontera, Temuco, Chile; <sup>4</sup>Foundation Eye Care Himalaya, Kathmandu, Nepal; and the <sup>5</sup>National Eye Institute, National Institutes of Health, Bethesda, Maryland.

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

1016 and median 1029), with an estimated 20% represented by children between the ages of 7 and 15 years.

Twenty-five clusters were randomly selected for the study sample: six each were in Bijanapally and Telkapalle mandals, five each in Gopalpet and Nagarkurnool mandals, and three in Tadoor mandal. Sample size was based on that estimated for the earlier studies,<sup>5</sup> with a 20% increase to accommodate lower examination response rates and larger cluster design effects.

## Field Operations

Fieldwork was performed between April 2000 and February 2001, proceeding in a cluster-by-cluster sequence. All field operations within a particular cluster, including clinical examinations, were generally completed within a 1-week period, before moving on to the next cluster.

Each cluster was mapped to identify all houses by three field investigators, followed by a household-to-household enumeration of eligible children. A community leader was contacted before the mapping by the field investigators to explain the purpose of the survey and to seek his or her support. Family members living and eating in the same premises were defined as a household. The study's purpose was explained to the man or woman of the household during the enumeration. The name, age (completed years), gender, years of schooling, and name of the school were collected for each child 7 to 15 years of age. Also, data on the schooling level of parents and whether eligible children were absent from the community were collected. The number of eligible children in each household and their availability were verified by querying neighbors. Visiting children (resident <6 months), institutionalized children, and those away for 6 months or more were not included in the study population.

A card with the scheduled date for the eye examination was given to the man or woman of the household for each eligible child. Children with spectacles were requested to bring them on the day of the examination. Written informed consent for the examination was obtained from the man or woman of the household after explaining the eye examination procedures, including the blurring of vision due to application of cycloplegic eye drops. Those who refused to participate in the study were contacted at least three times on separate occasions before they were deemed to be nonparticipants—twice within the 1-week period when the team was in the cluster and again toward the end of the study. Children were transported to the examination site on the scheduled date. Children who could not keep the scheduled date were given another date within the same week or were offered an examination near the end of the study. Age was verified before the examination process was initiated. Those who were found ineligible were offered an eye examination but were not considered to be study participants.

## Clinical Examination

Two ophthalmic technicians with prior experience of 5 and 3 years and one ophthalmologist with prior experience of 4 years performed all examination procedures in a clinic set up at the rural eye center specifically for the study. Examinations were generally performed during standard clinic hours and 6 days a week. Examination procedures have been described in detail elsewhere.<sup>5</sup>

In brief, the examination by the ophthalmic technicians included distance visual acuity measurements, ocular motility evaluation, and retinoscopy and autorefractometry after cycloplegia, as well as subjective refraction in those with uncorrected visual acuity of 20/40 or worse in either eye. Visual acuity was measured at 4 m, using a retroilluminated log minimum angle of resolution (MAR) chart with five E optotypes on each line (Precision Vision, La Salle, IL), and recorded as the smallest line read with one or no errors. The right eye was tested first and then the left, both with (presenting visual acuity) and without glasses (uncorrected visual acuity), if the child brought them. Lens power was measured with a lensometer. Ocular motility was evaluated at both 0.5

and 4.0 m. Tropias were categorized as esotropia, exotropia, or vertical, with the degree of tropia measured using the corneal light reflex. Pupils in each eye were dilated with 2 drops of 1% cyclopentolate with an interval of 5 minutes. After 20 minutes, if 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 was dilated to 6 mm or more and light reflex was absent. Refraction was performed in children after cycloplegic refraction, regardless of their visual acuity, using streak retinoscopy. Cycloplegic autorefractometry was performed using a handheld autorefractor (Retinomax K-Plus; Nikon Corp., Tokyo, Japan), with calibration at the beginning of each day. Subjective refraction was performed in children with uncorrected visual acuity of 20/40 or worse in either eye.

The study ophthalmologist evaluated the anterior segment using a slit lamp and the media and fundus using a slit lamp and indirect ophthalmoscope. The principal cause of visual impairment of 20/40 or worse was assigned after completion of the ocular examination, using a seven-item list (refractive error, amblyopia, corneal opacity due to trachoma, other corneal opacity, cataract, retinal disorder, other causes). Refractive error was recorded as the cause of visual impairment in eyes improving to 20/32 or better with refractive correction. Amblyopia was considered the cause of impairment in 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; and (3) bilateral ametropia of at least +6.00 spherical equivalent diopters.

Children whose vision improved with refractive error correction in either eye were prescribed and provided spectacles within 2 weeks of the examination. Children needing medical or surgical treatment were referred to the rural eye center for treatment.

Survey fieldwork was preceded by a pilot study in three nonstudy clusters in the district in February and March 2000. For 2 weeks before the pilot, the study team was trained in RESC procedures. Retraining was performed for visual acuity assessment and other procedures found to be difficult in younger children during the pilot study. Reproducibility of visual acuity measurements, objective refraction, and autorefractometry was assessed between the two ophthalmic technicians during the pilot.

The survey was approved by the Ethics Committee of the L. V. Prasad Eye Institute, Hyderabad, India. Human subject research approval for the study protocol was obtained from the World Health Organization Secretariat Committee on Research Involving Human Subjects. The research protocol adhered to the provisions of the Declaration of Helsinki for research involving human subjects.

## Data Management and Analysis

Enumeration and clinical data were recorded using precoded data-collection forms. A computer was used to check for data that were missing, inaccurate, or inconsistent at the completion of data entry for each cluster.<sup>11</sup>

Prevalence of visual impairment (visual acuity 20/40 or worse) and blindness (visual acuity of <20/200) was calculated for uncorrected visual acuity, baseline (presenting) visual acuity, 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 a spherical equivalent refractive error of at least  $-0.50$  D and hyperopia as  $+2.00$  D or more. A child was considered an emmetrope if neither eye was myopic or hyperopic, a myope if either or both eyes had myopia, and a hyperope if one or both eyes had hyperopia, so long as neither eye had myopia. Age-specific prevalences of myopia and hyperopia were estimated. Only children with cycloplegic dilation in both eyes were included in refractive error analyses. Association of refractive error with age and sex was explored by multiple logistic regression. In addition to these two variables, the

years of schooling of the father, as a surrogate for the socioeconomic status of the family, and years of schooling of the child were also included in the regression model. The father's schooling was categorized to correspond to distinct grade level achievement: none, 1 to 5 years, 6 to 12 years, 13 to 15 years, and more than 15 years. Pair-wise interactions between regression model variables were assessed simultaneously, using a Wald F test,<sup>11</sup> 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.<sup>11</sup> The magnitude of these effects is expressed by a ratio termed the design effect (deff), which compares the estimate of variance actually obtained with that that would have been obtained had the observations been collected through simple random sampling. 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 data were ignored in all analyses, and thus their distribution was implicitly assumed to be similar to that of available data.

### Quality Assurance

Seven clusters were preselected for reproducibility assessment for quality-assurance purposes. In these clusters, all children with uncorrected visual acuity of 20/40 or worse in either eye and approximately 10% of other children had second evaluations of uncorrected visual acuity, retinoscopy, and autorefractometry, which were conducted independently by the two ophthalmic technicians.

Visual acuity testing was repeated in 175 children, and refractive error measurements in 179 children. Visual acuity was distributed as follows: 2.3% of eyes had uncorrected visual acuity of 20/200 or worse, 6.3% had 20/160 to 20/80, 11.7% had 20/63 to 20/40, and 79.7% had 20/32 or better. These children were distributed across all ages. Reproducibility of both right-eye and left-eye visual acuity testing was good, with unweighted  $\kappa$  statistics of 0.83 and 0.88, respectively. Of the second right-eye measurements, 17 differed by one line and 1 by three lines. Fourteen of the left eye measurements differed by one line and none by more. Mean test-retest differences for cycloplegic retinoscopy was  $+0.016 \pm 0.289$  D for right eye measurements and  $+0.021 \pm 0.261$  D for left eyes. These differences were not significantly different from zero (paired  $t$ -test,  $P = 0.459$  and  $P = 0.283$ ). The 95% upper and lower limits of agreement around the mean of the differences between the two values<sup>12</sup> were  $-0.551$  to  $+0.583$  D for right eye measurements and  $-0.491$  to  $+0.533$  D for left eyes. Reproducibility of cycloplegic autorefractometry was equally good, with mean test-retest differences of  $+0.001 \pm 0.279$  D in right eyes and  $-0.006 \pm 0.307$  D in left eyes.

## RESULTS

### Study Population

A total of 4876 households were identified in 25 clusters, of which 2499 (51.2%) provided 4414 eligible children between 7 and 15 years of age. In households with eligible children, 47.4% had one such child, 33.7% had two, 14.9% had three, and 4.0% had four or more. The largest household had seven eligible children. The number of enumerated children per cluster ranged from 115 to 340.

Of these 4414 children, 4074 were examined—a participation rate of 92.3%. Eight additional children appeared at the examination site, but because neither visual acuity nor cycloplegic dilation and refractive measurement were possible, they were not included among the examined cohort. Examination response across the 25 clusters ranged from 81.2% to 98.3%. The distribution of the enumerated and examined children by age and gender is shown in Table 1. Girls had a somewhat better overall examination response rate: 93.3% compared with 91.4% in boys. Although there were differences in response rates across ages and gender, the distribution of the examined population was not significantly different from that of the enumerated population ( $\chi^2$  goodness of fit,  $P = 0.515$ ).

Approximately half of the examined children were attending school, including 84% of 7-year-olds. Twenty-four percent of children had never been in school. Three fourths (78%) of fathers had no formal schooling: 8% had 1 to 5 years, 13% 6 to 12 years, and 2% had 13 years or more. Ninety percent of mothers had no schooling.

### Visual Acuity

Uncorrected and baseline visual acuities (determined at initial examination) were available in 3994 (98.0%) children. Eighty children were not sufficiently cooperative for a proper measurement, and of these, 42 were 7 years of age. Uncorrected visual acuity of 20/32 or better in at least one eye was found in 3885 (97.3%), corresponding to 109 (2.7%) with acuity of 20/40 or worse in both eyes (Table 2). Seven (0.18%) children had visual acuity of 20/200 or worse in the better eye. Six (0.15%) had less than 20/200 in the better eye and were therefore blind according to the definition used in India. The distribution of uncorrected visual acuity did not differ significantly between boys and girls (Kolmogorov-Smirnov test,  $P = 0.914$ ).

Twenty-three children had spectacles at initial examination, six (26.1%) with baseline visual acuity of 20/40 or worse in at least one eye, including one child with visual acuity less than

TABLE 1. Distribution of Enumerated and Examined Children by Age and Sex

Age	Boys			Girls			All Children		
	Enumerated	Examined	% Examined	Enumerated	Examined	% Examined	Enumerated	Examined	% Examined
7	324 (14.0)	307 (14.5)	94.7	293 (13.9)	281 (14.3)	95.9	617 (14.0)	588 (14.4)	95.3
8	318 (13.8)	302 (14.3)	95.0	336 (16.0)	324 (16.5)	96.4	654 (14.8)	626 (15.4)	95.7
9	247 (10.7)	231 (10.9)	93.5	253 (12.0)	240 (12.2)	94.9	500 (11.3)	471 (11.6)	94.2
10	286 (12.4)	261 (12.4)	91.3	259 (12.3)	246 (12.5)	95.0	545 (12.3)	507 (12.4)	93.0
11	254 (11.0)	239 (11.3)	94.1	216 (10.3)	208 (10.6)	96.3	470 (10.6)	447 (11.0)	95.1
12	316 (13.7)	283 (13.4)	89.6	274 (13.0)	251 (12.8)	91.6	590 (13.4)	534 (13.1)	90.5
13	197 (8.5)	174 (8.2)	88.3	207 (9.8)	184 (9.4)	88.9	404 (9.2)	358 (8.8)	88.6
14	180 (7.8)	164 (7.7)	91.1	143 (6.8)	121 (6.2)	84.6	323 (7.3)	285 (7.0)	88.2
15	190 (8.2)	152 (7.2)	80.0	121 (5.8)	106 (5.4)	87.6	311 (7.0)	258 (6.3)	83.0
All	2312 (100.0)	2113 (100.0)	91.4	2102 (100.0)	1961 (100.0)	93.3	4414 (100.0)	4074 (100.0)	92.3

Data are number enumerated and examined with percentage of total 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	3793 (95.0; 94.3–95.6)	11 (0.29)	3799 (95.1; 94.5–95.8)	3897 (97.5; 97.1–97.9)
≥20/32 in one eye	92 (2.30; 1.76–2.85)	2 (2.17)	92 (2.30; 1.76–2.85)	69 (1.73; 1.34–2.11)
≤20/40 to ≥20/63 in the better eye	73 (1.83; 1.22–2.43)	2 (2.74)	74 (1.85; 1.20–2.50)	20 (0.50; 0.29–0.71)
≤20/80 to ≥20/160 in the better eye	29 (0.73; 0.47–0.98)	8 (27.6)	21 (0.53; 0.32–0.73)	6 (0.15; 0.06–0.33)*
≤20/200 in the better eye	7 (0.18; 0.07–0.36)*	0	8 (0.20; 0.09–0.39)*	5 (0.13; 0.04–0.29)*
All	3994 (100.0)	23 (0.58)	3994 (100.0)	3997 (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 1.008 to 1.287 are not reflected in the confidence intervals for the four exact binomial estimates. Design effects ranging from 0.620 to 2.185 were taken into account in calculating confidence intervals for estimates based on the normal approximation.

20/200 in the better eye. Among those with uncorrected visual acuity of 20/40 or worse in both eyes, ten (9.2%) were wearing glasses. Because so few children were wearing glasses, baseline acuity was essentially the same as uncorrected visual acuity. In 103 (2.6%) children, acuity was 20/40 or worse in both eyes, including 7 (0.18%) children who were blind, with acuity less than 20/200 in the better eye. The additional case of blindness with baseline acuity was because the one child with visual acuity of less than 20/200 in both eyes with spectacles had uncorrected visual acuity better than 20/200 in the better eye when the glasses were removed.

Best corrected visual acuity measurement was available in 3997 (98.1%) children, of whom 31 (0.78%) had visual acuity of 20/40 or worse in both eyes. Accordingly, 1.8% of all children examined had improved baseline visual acuity to 20/32 or better in at least one eye with prescription glasses. Five children (0.12%) remained blind after best correction: one because of bilateral corneal opacities after high fever in early childhood, two because of bilateral retinal disorders (heredomacular degeneration), one because of congenital anomaly (coloboma of the disc and macula), and one because of stimulus-deprivation amblyopia due to nystagmus.

## Refractive Error

Refractive error was analyzed in the 3976 (97.6%) children with cycloplegic dilation in both eyes, including 407 children in whom the pupil did not dilate fully to 6 mm in one or both eyes, but the pupillary light reflex was absent in both eyes. Cycloplegic dilation in one or both eyes was not achieved in 98 examined children because of poor cooperation. Data in these cases were not included in the analyses of refractive error. The distribution of mean spherical equivalent in the right eyes of boys and girls by cycloplegic retinoscopy is shown in Figure 1. Mean refractive error for all ages was +0.54 D in boys and +0.56 D in girls. Mean spherical equivalents were similar in the left eye (data not shown). A gradual shift toward less-positive spherical equivalents was seen with increasing age in both boys and girls. Refractive error varied considerably within each age cohort, as shown by the large SDs.

Figure 2 shows the distribution of refractive error in right eyes in different age groups. Across all ages, hyperopia was found in 0.43% of right eyes and myopia in 3.8% (data not shown).

The age-specific prevalences of hyperopia and myopia measured with cycloplegic retinoscopy are shown in Table 3. Overall, 31 children had hyperopia, a prevalence of 0.78% (95% CI, 0.49%–1.07%; *deff* = 0.983), and 163 children had myopia, representing a prevalence of 4.1% (95% CI, 3.3%–4.9%; *deff* = 1.562). With cycloplegic autorefraction, hyperopia was present in 27 children, a prevalence of 0.68% (95% CI,

0.40%–0.96%; *deff* = 1.085), and myopia was present in 222 children, a prevalence of 5.6% (95% CI, 4.7%–6.5%; *deff* = 1.458). 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 1.3% (95% CI, 0.92%–1.5%; *deff* = 0.878). Hyperopia of +4.00 D or more in at least one eye was found in 0.33% (95% CI, 0.13%–0.53%; *deff* = 1.137) of the children.

In multiple logistic regression modeling, myopia with retinoscopy was associated with female gender (odds ratio [OR], 1.46; 95% CI, 1.04%–2.06%), older age (OR, 1.10; 95% CI, 1.00%–1.20%), and increasing levels of schooling of the father (OR, 1.48; 95% CI, 1.16%–1.89%). The years of schooling of the child was not significant (*P* = 0.633). In regression modeling for severe myopia, schooling of the father was associated with an increased risk. No significant associations were found in the multiple-regression modeling for hyperopia. Modeling for both myopia and hyperopia using autorefraction data produced similar findings.

The distribution of astigmatism by cycloplegic retinoscopy and cycloplegic autorefraction is shown in Table 4. Astigmatism of 0.75 D or more was found in 2.8% of right eyes and 2.9% of left eyes with retinoscopy. With autorefraction, the prevalence increased to 5.9% in right eyes and 6.3% in left eyes. The higher prevalence with autorefraction was caused by an increase in mild levels of astigmatism. Astigmatism in one or both eyes was present in 3.8% of children with retinoscopy and in 9.7% with autorefraction. The more severe level of astigmatism (at least 2.00 D) affected 1.0% of children when measured with retinoscopy and 1.2% when measured with autorefraction. In multiple logistic regression, astigmatism in the right eye was associated with female gender with both retinoscopy and autorefraction (*P* = 0.006 and *P* = 0.028, respectively) and with older age with retinoscopy (*P* = 0.011). In left eyes, astigmatism was associated with older age (*P* = 0.034 and *P* = 0.012) but not with gender (*P* = 0.171 and *P* = 0.084). Astigmatism was associated with older age with both methods (*P* = 0.003 and *P* = 0.033) and with female gender with autorefraction (*P* = 0.063, retinoscopy; *P* = 0.033, autorefraction). Age and gender were not predictors of astigmatism greater than 2.00 D with either method.

Although spherical equivalent refractive error measurements from retinoscopy and autorefraction were highly correlated (Pearson correlation of 0.95 for right eyes and 0.94 for left eyes), autorefraction tended to produce more negative readings. There was a mean difference of  $-0.131 \pm 0.247$  D (SD) in right-eye measurements and  $-0.109 \pm 0.254$  D in left eyes, both statistically significant (paired *t*-test, *P* < 0.001). The 95% limits of agreement between the two methods were –0.615 and +0.353 D in right-eye measurements, and –0.607 and

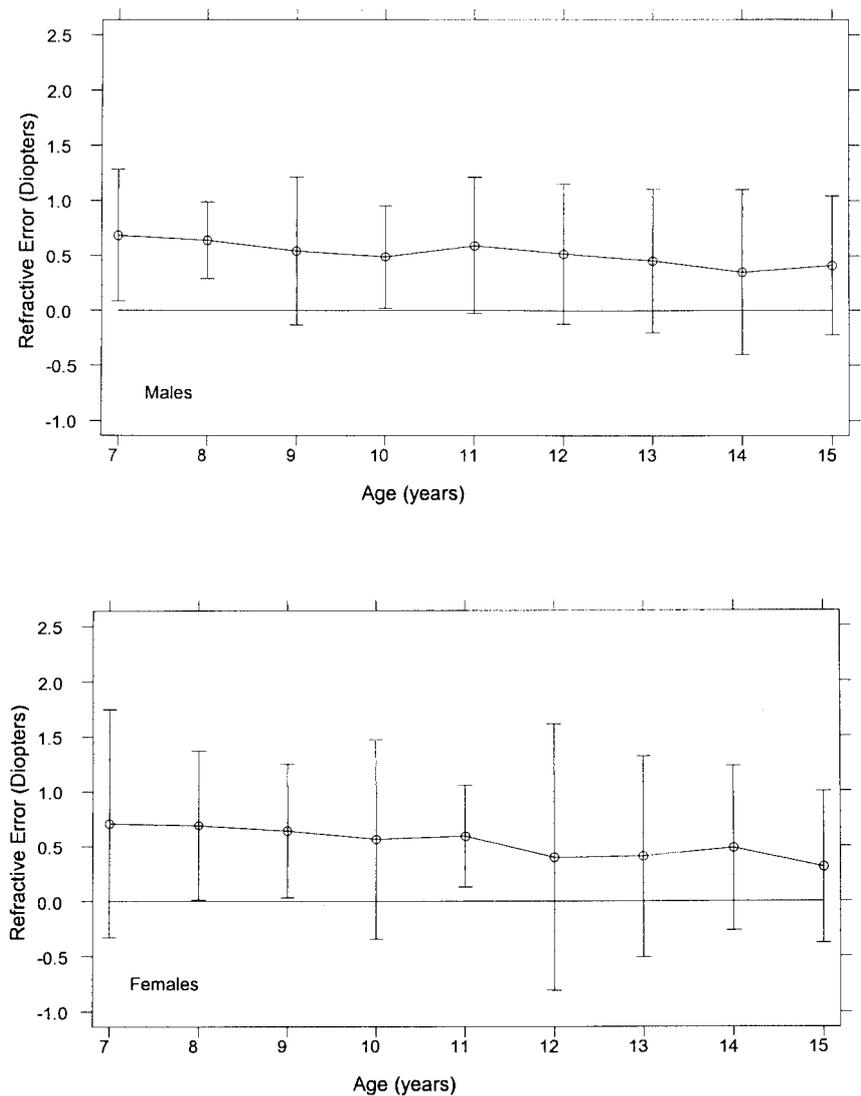


FIGURE 1. Mean right-eye spherical equivalent refractive error by age in boys (*top*) and girls (*bottom*). Vertical bars: SDs.

+0.390 in left-eye measurements. The systematic difference between retinoscopy and autorefractometry was present across both negative and positive retinoscopy measurements.

### Other Ocular Abnormalities

Tropia for distance was present in 74 (1.8%) examined children and for near in 76 (1.9%). Most of the tropia was exotropia, 72% for distance and 71% for near, and was 15° or less (65% for distance and 63% for near).

Eyelid abnormalities (mainly blepharitis) were observed in 53 eyes of 38 (0.93%) children. Conjunctival abnormalities were present in 366 eyes of 208 (5.1%) children, including 301 eyes in 158 (3.9%) children with Bitot spots. Corneal abnormalities were observed in 21 eyes of 16 (0.39%) children. Pupillary abnormalities were noted in 18 eyes of 15 (0.37%) children. Lenticular abnormalities were present in 13 eyes of 10 (0.25%) children, including 1 child with a pseudophakic eye and another with traumatic aphakia. Fundus abnormalities were seen in 70 eyes of 49 (1.2%) children.

### Causes of Visual Impairment

Table 5 shows causes of visual impairment identified by the examining ophthalmologist in the 300 eyes with uncorrected visual acuity of 20/40 or worse, involving 200 children. In

more than half of the children, the reduced visual acuity was because of refractive error. Amblyopia, satisfying the predefined criteria, was the cause of uncorrectable vision impairment in another 31 (15.5%) children: 23 with tropia, 15 with anisometropia, and 1 with bilateral hyperopia. In another 24 eyes of 16 children, the criteria were not met, but the examining ophthalmologist concluded that amblyopia was the most likely cause of vision impairment. These cases are included among the unexplained causes in Table 5. Retinal disorders (including retinitis pigmentosa, coloboma, macular scar, and heredomacular degeneration) and corneal opacity and scars were the other significant causes of visual impairment.

### DISCUSSION

RESC was a population-based cross-sectional survey of school-aged children between 7 and 15 years of age in a rural population of Andhra Pradesh in India. The major difference between this RESC survey and the others,<sup>6-9</sup> with which it can be compared, is that the sample was drawn from children between 7 and 15 years of age, rather than 5 and 15 years. Five- and 6-year-olds were included in the pilot survey, in which it was realized that children at these ages were finding it very difficult to comprehend the visual acuity test—particularly,



FIGURE 2. Distribution of spherical equivalent refractive error in right eyes of children aged 7 to 10, 11 to 13, and 14 to 15 years. Data points represent a 1-D interval (for example, those associated with +1 on the x-axis represent more 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.

those without prior schooling experience. Because many of these visual acuity measurements would not have been accurate, a decision was made to exclude children of these ages from the study sample.

Although the age and gender distribution of the enumerated population could not be validated because up-to-date census data were unavailable, it is possible that a significant number of children aged 13 to 15 years in families resident in the cluster were not enumerated because of temporary absence from the area. This happened despite explicit inquiry during the enumeration process regarding such children. Drought conditions that were prevailing in Andhra Pradesh during this time contributed to this possibility. The major occupation in Mahabubnagar district is agriculture, which was seriously affected by the drought. To help households survive financially, children 13 years of age and older may have temporarily moved to cities with their fathers to look for work, where, through manual labor, they could contribute to the sustenance of the household. In other cases, entire households may have relocated to cities—particularly those with children in this employable age range. Although not representing incomplete enumeration of children with residence remaining in Mahabubnagar district, it would have contributed to the deficit of children 13 to 15 years of age.

The overall examination participation rate was 92.3%, with participation the lowest among older children. Again, older

children were more likely to be unavailable for examination, even though they may have been enumerated. To improve the participation rate in this age group, the field team revisited households toward the end of the study. However, this had limited success in increasing response rates. The combination of migration, underenumeration, and lower examination participation among 13- to 15-year-olds may have introduced biases that could have affected study results in some unsuspected way.

Clustering of refractive error associated with environmental or genetic influences within families<sup>13</sup> or within the larger geographically defined cluster is embedded in the study findings. Clustering effects were taken into account in the calculation of confidence intervals for prevalence estimates and in regression analyses. The familial component of clustering should be of no consequence in estimates dealing with 1-year age intervals, because a family is unlikely to have more than one child at the same age, but it could be important in analyses dealing with multiyear age intervals. In general, cluster design effects as represented by design effect values seldom greater than 1.5 were modest and thus had little impact on the statistical power of the survey.

Baseline (presenting) visual acuity of 20/40 or worse in at least one eye was found in 4.9% of the study population, which decreased to 2.5% with best corrected vision. For visual acuity 20/40 or worse in the better eye (i.e., both eyes), the respective percentages were 2.6% and 0.78%. With uncorrected visual acuity, 2.7% had acuity worse than 20/40 in the better eye. These findings illustrate the potential benefit of spectacles in 70% of the children who had bilateral vision impairment and in 50% of those with visual acuity of 20/40 or worse in at least one eye. This unmet need for spectacles among school-aged children replicates that reported in other RESC studies, including that in New Delhi.<sup>6-9</sup>

The prevalence of baseline visual acuity of 20/40 or less in the better eye in the urban population in New Delhi, 4.9%, was nearly double the 2.6% found in the rural population of Mahabubnagar district. Although with best corrected vision the prevalence of impairment was similar in urban and rural populations, blindness remained nearly twice as high in the rural population as in the urban population with both baseline and best corrected visual acuity. The burden of visual impairment in both urban and rural populations was mostly due to refrac-

TABLE 3. Prevalence of Ametropia by Age with Cycloplegic Retinoscopy

Age (y)	Myopia* (%; 95% CI)	Hyperopia† (%; 95% CI)
7	2.80; 1.28-4.33	0.70; 0.03-1.37
8	2.83; 1.50-4.16	0.33; 0.00-0.81
9	3.90; 2.05-5.74	0.43; 0.00-1.05
10	4.06; 2.09-6.03	1.21; 0.15-2.28
11	2.73; 1.38-4.09	1.59; 0.39-2.80
12	4.79; 2.91-6.97	0.77; 0.00-1.53
13	5.43; 3.25-7.60	0.57; 0.00-1.40
14	6.74; 3.31-10.2	0.35; 0.00-1.07
15	6.72; 4.31-9.12	1.18; 0.00-2.58

\* Cluster design effects ranged from 0.548 to 1.281.

† Cluster design effects ranged from 0.868 to 1.091.

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	3861 (97.2)	3852 (97.0)	3823 (96.2)	3735 (94.1)	3718 (93.7)	3585 (90.3)
≥0.75 to <2.00	87 (2.2)	87 (2.2)	110 (2.8)	209 (5.3)	218 (5.5)	341 (8.6)
≥2.00	25 (0.63)	30 (0.75)	40 (1.0)	26 (0.65)	32 (0.81)	46 (1.2)
All	3973 (100.0)	3969 (100.0)	3973 (100.0)	3970 (100.0)	3968 (100.0)	3972 (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.

tive error. The prevalence of uncorrected visual acuity of 20/40 or less in the better eye because of refractive error was 1.9% in the rural population, compared with 5.6% in the urban population of New Delhi. The difference in visual impairment at initial examination between these urban and rural populations would have been even greater, approaching a threefold difference, had not a higher percentage of children in the urban population had correction for refractive error—26.8% versus 5.3% in the rural population. These data highlight the need for refractive error correction in school-aged children in India.

The overall prevalence of myopia of  $-0.50$  D or worse in this study was 4.1%, which is higher than the 1.2% reported in children 5 to 15 years of age from rural Nepal, but less than that reported from China (16.2%), Chile (6.8%), and New Delhi (7.4%).<sup>6-9</sup> Myopia was associated with female gender and older age, which was also found in New Delhi and China. The association of myopia with the father's schooling was found in both this and the New Delhi survey. Children from families led by parents with higher levels of educational attainment, and probably greater resources, may experience more pressure to study, entailing near work, which in turn could cause the onset of myopia.<sup>14,15</sup> (Information on the schooling of parents was not collected in the earlier surveys in Nepal, China, and Chile.)

The prevalence of hyperopia of  $+2.00$  D or more was 0.78%, less than the 1.4%, 3.5%, 16.3%, and 7.7% reported in children 5 to 15 years of age from Nepal, China, Chile, and New Delhi, respectively.<sup>6-9</sup> Review of age-specific data (Table 3) indicates that this low prevalence is not explained by the exclusion of 5- and 6-year-olds in this rural population. There were no significant associations of age or gender with hyperopia. The age-related shift from hyperopia to myopia was not as prominent in our study population as in the urban population

in New Delhi, which could be related to the increased intensity of schooling in the urban population compared with that in our rural population.

The prevalence of astigmatism of 0.75 D or more (2.8%) was comparable with the 2.2% reported in children from Nepal,<sup>7</sup> lower than the 5.4% reported in New Delhi,<sup>9</sup> and much lower than the 15% and 19% reported in China,<sup>6</sup> and Chile,<sup>8</sup> respectively. Autorefraction yielded higher levels of astigmatism, as was the case in all but China.

Notable differences in the prevalence of myopia, hyperopia, and astigmatism were found between this rural population and the urban population in New Delhi. Because of the cross-sectional nature of these studies, it is possible to comment only on the association between refractive error prevalence and possible risk factors, and not on the more specific causes. Observed differences in the schooling of both children and parents, specifically fathers, represents one possible explanation for the differences in refractive error between the rural and urban populations studied. The association of myopia with the father's educational level may represent an environmental effect, as well as a genetic one if fathers with myopia are more likely to have higher levels of schooling.<sup>16</sup> Although the influence of environment on myopia, separate from genetic influences, cannot be addressed using these data, the apparent importance of schooling intensity on the prevalence of myopia is clearly highlighted by these studies.

As noted in the companion article, there are a large number of articles on childhood refractive error in the literature,<sup>17</sup> reporting a broad, worldwide variation in the prevalence of myopia and hyperopia. Substantial differences in methods, definitions, and demographics, however, preclude meaningful detailed comparisons with our data.

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 of 20/40 or Worse (One or Both Eyes)	Percentage Prevalence in Population (One or Both Eyes)*
	Right Eye	Left Eye		
Refractive error†	94 (66.2)	88 (55.7)	106 (53.0)	2.65
Amblyopia‡	13 (9.2)	23 (14.5)	31 (15.5)	0.78
Corneal opacity	8 (5.6)	6 (3.8)	13 (6.5)	0.32
Cataract	1 (0.70)	0	1 (0.5)	0.03
Retinal disorder	8 (5.6)	15 (9.5)	16 (8.0)	0.40
Other causes	4 (2.8)	2 (1.3)	6 (3.0)	0.15
Unexplained cause§	14 (9.8)	24 (15.2)	27 (13.5)	0.68
Any cause	142 (100.0)	158 (100.0)	200 (100.0)	5.00

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 24 eyes of 16 children in whom the examining ophthalmologist concluded that amblyopia was the probable cause of impairment, but the amblyopia criteria were not met.

Cycloplegic retinoscopy and cycloplegic autorefractometry demonstrated good reproducibility. Measurement pairs were within 0.5 D for both retinoscopy and autorefractometry 95% of the time, with insignificant mean differences. Agreement between the two methods was also within 0.5 D 95% of the time. Autorefractometry produced marginally more negative measurements than retinoscopy, suggesting that cycloplegia may have been incomplete in some children. The mean differences of 0.13 and 0.11 D for right and left eyes, respectively, are clinically insignificant. More negative measurements with autorefractometry were also recorded in the Chinese study.<sup>6</sup> Visual acuity testing was also highly reliable.

Refractive error was shown to be the leading cause of visual impairment among rural children 7 to 15 years of age, accounting for 68.5% of impairment, with amblyopia included. (To estimate the complete burden of refractive error, refractive error-related amblyopia should also be taken into account.) In a previous survey of people of all ages in Andhra Pradesh, including Mahabubnagar district, refractive error was also shown to be the major cause of moderate visual impairment and the second leading cause of blindness.<sup>18,19</sup> Data from the Andhra Pradesh survey suggest that 0.18% of rural school-age children are blind (baseline visual acuity <20/200 in the better eye) and another 2.4% are visually impaired (baseline visual acuity 20/40–20/200 in the better eye), but that these proportions can be reduced to 0.13% and 0.65%, respectively, with the use of refractive correction. The findings in this survey are comparable with the ones obtained in the current study.

From a public health perspective, vision screening is an appropriate strategy to reduce vision impairment. Most of this impairment is caused by refractive error, for which treatment is simple, effective, and inexpensive. A few factors should be considered, however, in establishing screening programs: First, vision screening should take place only if adequately trained personnel are available who can perform refraction of reasonable quality in children identified with vision impairment. Second, provision of good-quality and affordable spectacles should be an integral part of the vision-screening program. Third, an attempt should be made to include all school-aged children, not just school-attending children, because many of the children in developing countries do not attend schools.<sup>4</sup> Fourth, target populations should be prioritized using available population-based data on the age distribution of refractive error. Data from RESC surveys suggest that children, beginning at the ages of 11 or 12 years, should be the initial priority of screening programs, because the prevalence of myopia appears to increase markedly around this age.

In conclusion, significant visual impairment due to refractive error was found among school-aged children living in a rural district of southern India. Because most refractive error can be easily corrected with spectacles and because visual impairment can have a detrimental impact on education and development in a child's life, cost-effective strategies to elimi-

nate this easily treatable cause of visual impairment are warranted.

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