Refractive Error and Visual Impairment in African Children in South Africa

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Purpose. To assess the prevalence of refractive error and visual impairment in school-aged African children in South Africa.

Methods. Random selection of geographically defined clusters was used to identify a sample of children 5 to 15 years of age in the Durban area. From January to August 2002, children in 35 clusters were enumerated through a door-to-door survey and examined in temporary facilities. The examination included visual acuity measurements, ocular motility evaluation, retinoscopy and autorefraction under cycloplegia, and examination of the anterior segment, media, and fundus. In nine clusters, children with reduced vision and a sample of those with normal vision underwent independent replicate examinations for quality assurance.

Results. A total of 5599 children living in 2712 households were enumerated, and 4890 (87.3%) were examined. The prevalence of uncorrected, presenting, and best-corrected visual acuity of 20/40 or worse in the better eye was 1.4%, 1.2%, and 0.32%, respectively. Refractive error was the cause in 63.6% of the 191 eyes with reduced vision, amblyopia in 7.3%, retinal disorders in 9.9%, corneal opacity in 3.7%, other causes in 3.1%, and unexplained causes in the remaining 12.0%. Exterior and anterior segment abnormalities were observed in 528 (10.8%) children, mainly corneal and conjunctival. Myopia (at least −0.50 D) in one or both eyes was present in 2.9% of children when measured with retinoscopy and in 4.0% measured with autorefraction. Beginning with an upward trend at age 14, myopia prevalence with autorefraction reached 9.6% at age 15. Myopia was also associated with increased parental education. Hyperopia (+2.00 D or more) in at least one eye was present in 1.8% of children when measured with retinoscopy and in 2.6% measured with autorefraction, with no significant predictors of hyperopia risk.

Conclusions. The prevalence of reduced vision is low in school-age African children, most of it because of uncorrected refractive error. The high prevalence of corneal and other anterior segment abnormalities is a reflection of the inadequacy of primary eye care services in this area. (*Invest Ophthalmol Vis Sci.* 2003;44:3764–3770) DOI:10.1167/iovs.03-0283

A global coalition of nongovernmental organizations (NGOs) and the World Health Organization (WHO) recently launched the "Vision 2020: The Right to Sight" initiative. Correction of refractive errors is included in the strategy for the elimination of avoidable visual impairment and blindness. Although studies have been conducted in various countries to further understanding of the nature and magnitude of the refractive error problem, most were performed in settings of unknown representativeness.[1] Also, because of different measurement methods and nonuniform definitions, comparisons across study reports are generally not possible.[1]

Beginning in 1998, a series of population-based surveys of refractive error and visual impairment in school-aged children were conducted, all using the same protocol.[2] These Refractive Error Study in Children (RESC) surveys were performed in populations with different ethnic origins and cultural settings: a rural district in eastern Nepal[3]; a semirural county outside of Beijing, China[4]; an urban area of Santiago, Chile[5]; a rural district near Hyderabad, India[6]; and an urban area of New Delhi, India.[7] This article reports on the implementation and findings from a sixth such survey, conducted in Durban, South Africa.

The survey was motivated by the paucity of refractive error data to guide the efficient mobilization of refractive and eye care services in South Africa and elsewhere on the African continent. Although the availability of eye care personnel in South Africa is much better than the rest of Africa, particularly with regard to optometrists, poor distribution has resulted in most of the population's finding refractive services inaccessible or unaffordable.[8–10] Optometrists practice almost exclusively in the private sector, whereas ophthalmologists focus mainly on the management of ocular disease and surgery and provide little with regard to refractive services. Ophthalmic nurses with training in basic refraction techniques are often deployed to eye care services other than refraction. The availability of refractive services in the public sector is thus very limited.

Methods

Sample Selection

The Durban metropolitan area, on the east coast of South Africa, is in the province of Kwazulu-Natal. The province had a 1996 census population of 8,417,021: 9.4% Indian/Asian; 6.6% white; 1.4% colored (mixed race); and the remaining 82% African/black.[11] Forty-three percent of the Kwazulu-Natal population lives in urban areas.[11]

A geographically contiguous area within the South Region, the Inner West Region, and the Outer West Region of the Durban metropolitan area was identified for the survey. The South and Inner West Regions are urban with both developed and underdeveloped, previously disadvantaged, areas. The Outer West Region is semirural to

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rural. The socioeconomic level ranges from middle in Durban South to low in the Outer West.

Cluster sampling was used to select the study population. Clusters were defined geographically using "enumerator areas" (EAs) created during the 1996 census, generally consisting of 100 to 250 dwelling units. EA boundaries used Global Positioning System (GPS) coordinates. Based on census estimates of children residing within each of the 385 EAs constituting the survey area, small EAs were grouped and larger ones subdivided in defining 537 clusters for the sampling frame, each with an estimated 150 to 299 children.

Initially, 26 clusters were randomly selected, with a census estimate of 5749 children between the ages of 5 and 15 years, exceeding the originally calculated 5200 sample size requirement.[2] However, early in the course of the enumeration it became apparent that the number of children would fall far short of what had been anticipated, particularly in clusters representing segments of subdivided EAs. Accordingly, enumeration was extended to households in the nonselected portion of the subdivided EA, resulting in the addition of nine clusters geographically adjacent to randomly selected ones.

Field Operations

Fieldwork for the main study took place from January to August 2002, after city councilors, traditional leaders, and other key community figures were approached for support. Given the crime in the area, it was necessary to elicit their endorsements and to produce a letter to this effect for use during the house-to-house enumeration. Because the study was being conducted while school was in session, the support of school administrators was also elicited.

Five enumerators were involved in the study. One enumerator and the fieldwork manager worked in advance of the enumeration team, mapping the boundaries of the selected clusters using a handheld device to access GPS coordinates. The enumeration of households within each cluster generally took 3 days. On completion, two members of the enumeration team stayed behind to transport children to the examination site and assist the clinical team, while the others moved to the next scheduled cluster.

All households were visited up to three times if necessary, and children of ages 5 to 15 years were enumerated as to name, age, and gender. Children temporarily absent from the area (for up to 6 months) were included, nonresident visitors and guests were not. Years of school completed and the name of the current school was recorded for each child. The educational level of both parents was also obtained.

During the enumeration interview, the head of the household was informed of the details of the study, including the side effects of dilation; was asked to sign a consent form; and was informed of the date of the clinical examination. In situations where a child needed transportation to the examination site, a letter authorizing this was also signed.

Clinical Examination

Clinical examinations were conducted by four optometrists and one ophthalmologist in 37 temporary stations in school classrooms, community clinics, or community halls. Examination procedures followed the original RESC protocol.[2]

In brief, distance visual acuity was measured using a retroilluminated chart with tumbling-E optotypes. Ocular motility was evaluated with a cover test, and the degree of tropia measured using corneal light reflex and neutralizing prisms. After administration of a topical anesthetic (benoxinate 0.4%), cycloplegia was attained with 2 drops of 1% cyclopentolate (multidose applicator), administered 5 minutes apart, with a third drop administered after 20 minutes. Pupils were considered fully dilated if 6 mm or greater, and cycloplegia was evaluated with light reflex. Refraction was performed first with a streak retinoscope (Welch-Allyn, Skaneateles, NY) at 50 cm, using a picture fixation target at 4 m, and then with a handheld autorefractor (Retinomax K-Plus; Nikon, Tokyo, Japan). Subjective refraction was performed on children with uncorrected visual acuity of 20/40 or worse. (The end point was determined by the best visual acuity attainable with maximum plus, in 0.25-D increments.) The anterior segment was evaluated with a magnifying loupe. Examination of the media and fundus was performed with a slit lamp and indirect ophthalmoscope. A principal cause of visual impairment was assigned for all eyes with uncorrected visual acuity of 20/40 or worse. Refractive error was assigned if acuity improved to 20/32 or better with refractive correction.

Human subject approval for the study protocol was obtained from the WHO Secretariat Committee on Research Involving Human Subjects. The ethics committee of the University of Durban-Westville approved the study in Durban. The research protocol adhered to the provisions of the Declaration of Helsinki for research involving human subjects.

Pilot Study

Fieldwork was preceded by training and a pilot study conducted outside the main study area. In the pilot, 430 children from 224 households were enumerated and 386 examined. The pilot study revealed weaknesses in the reliability of visual acuity measurements and retinoscopic refraction. Malingering in an attempt to obtain spectacles, for example, was one of the difficulties faced in accurately measuring visual acuity. To alleviate this, children were informed that methods were in place to check for malingering, and if they wanted glasses, for any reason, they would receive them. Lack of test–retest reproducibility for retinoscopy measurements was addressed with further training and replacement of personnel. A second pilot involving only clinical procedures was performed to confirm the effectiveness of remedial actions.

Data Management and Analysis

Household enumeration and clinical examination data forms were reviewed for accuracy and completeness in the field before they were sent to the University of Durban-Westville for computer data entry. Data ranges, frequency distributions, and consistency among related measurements were checked with data cleaning programs. Statistical analyses were performed using computer software (Stata Statistical Software, Release 8.0; Stata, College Station, TX).[12]

Myopia was defined as spherical equivalent refractive error of at least −0.50 D and hyperopia as +2.00 D or more. The association of myopia or hyperopia with the child's age and gender and the parent's years of schooling (taken as a surrogate for the socioeconomic status of the family) were explored with multiple logistic regression modeling. Parental schooling, categorized to correspond to distinct grade level achievement (none, 1–5, 6–12, 13–15, and >15), was based on the parent with the highest education.

Confidence intervals were calculated with adjustment for clustering effects associated with the sampling design.[12] These design effects are quantified by a ratio, termed deff, comparing the estimate of variance actually obtained with the generally smaller variance that would have been obtained with simple random sampling.

Quality Assurance

In nine clusters, scheduled throughout the course of the study, children with uncorrected visual acuity of 20/40 or less and approximately 10% of those with normal or near normal vision were subjected to independent reevaluation of visual acuity, retinoscopy, and autorefraction. Visual acuity data were obtained for 214 of the 217 children subjected to these quality assurance evaluations. Of right eye measurements, 180 had line-by-line agreement, 31 differed by 1 line, 1 by 2 lines, and 2 by 3 lines. For left eyes, 173 measurements were in agreement, 37 differed by 1 line, and 4 by 2 lines. The κ statistics were 0.62 for right eyes and 0.60 for left eyes. With weighted κ, giving half weight to 1-line disagreement, the respective statistics were 0.71 and 0.72.

Mean test–retest differences (the first measurement minus the second one) for cycloplegic retinoscopy were -0.019 ± 0.292 D (SD) in 212 right eyes and -0.016 D $\pm$ 0.301 in 212 left eyes. Neither

Table 1. Enumerated and Examined Population by Age

Age (y)	Enumerated n (%)	Enumerated % Examined	Examined n (%)	Examined % with VA Measurement
5	461 (8.2)	73.5	339 (6.9)	64.3
6	527 (9.4)	86.9	458 (9.4)	87.8
7	522 (9.3)	89.8	469 (9.6)	96.4
8	528 (9.4)	89.2	471 (9.6)	98.7
9	503 (9.0)	93.3	469 (9.6)	99.4
10	601 (10.7)	91.7	551 (11.3)	99.6
11	528 (9.4)	91.5	483 (9.9)	100.0
12	535 (9.6)	89.0	476 (9.7)	99.6
13	478 (8.5)	87.9	420 (8.6)	99.8
14	496 (8.9)	86.3	428 (8.8)	99.5
15	420 (7.5)	77.6	326 (6.7)	99.7
Total	5599 (100.0)	87.3	4890 (100.0)	95.7

difference was significantly different from zero (paired *t*-test, $P = 0.174$ and $P = 0.221$). The 95% upper and lower limits of agreement around mean differences were −0.592 to +0.554 D for right eyes and −0.606 to +0.574 D for left eyes. Reproducibility for autorefraction was comparable, with mean test–retest differences of +0.015 ± 0.255 D (SD) for 217 right eyes and +0.006 ± 0.220 D for 215 left eyes. Again, neither of these differences was significantly different from zero (paired *t*-test, $P = 0.194$ and $P = 0.349$). The 95% limits of agreement for cycloplegic autorefraction were −0.484 to +0.514 D and −0.425 to +0.436 D, respectively.

Results

Study Population

In the 35 study clusters, 6351 households were identified. Interviews were possible in 6041 households: 5174 were interviewed on the first visit, 637 on the second, and 230 on the third. Of the 310 units where it was not possible to conduct interviews, 262 were found unoccupied after three visits and 48 households continually refused to participate. In the interviewed households, 3329 (55.1%) had no eligible children, 1086 (40.0%) had one child, 887 (32.7%) had two, and 739 (27.2%) had three or more. In total, 5599 eligible children were enumerated.

The age distribution of the enumerated population is shown in Table 1. Boys represented 49.3% of the total. Examinations were conducted in 87.3% of enumerated children: 86.6% in boys and 88.0% in girls.

Visual Acuity

Reliable visual acuity testing was not possible in 211 of the 4890 examined children, leaving 95.7% with visual acuity measurements in at least one eye (Table 1). Reliable measurements were obtained in 95.9% of boys and in 95.4% of girls.

Visual acuity findings are presented in Table 2. Uncorrected visual acuity of 20/32 or better in at least one eye was found in 4616 (98.7%) children. Sixty-three (1.4%) children had uncorrected vision of 20/40 or worse in the better eye, with five blind in both eyes. Boys had marginally poorer uncorrected visual acuity (Kolmogorov-Smirnov test, $P = 0.057$).

Twenty children wore glasses to the examination, including one in whom reliable testing was not possible. Seven of the 19 had normal/near-normal vision without glasses (Table 2). Of the 63 children with visual impairment of 20/40 or worse in the better eye, 12 (19.0%) were wearing glasses.

Fifty-five children (1.2%) had visual acuity of 20/40 or worse in the better eye. With best measured vision, this decreased to 15 (0.32%). Of the five who were blind, one (with bilateral hypopigmented iris and foveal hypoplasia) remained blind with best correction.

Pupillary Dilation

Pupillary dilation of at least 6 mm and the absence of light reflex were achieved in 2330 (47.6%) right eyes, dilation only in 1682 (34.4%) eyes, and absent light reflex without full dilation in 94 (1.9%) eyes, for a total of 4106 (84.0%) right eyes satisfying one or both criteria for "cycloplegic dilation" (Table 3). In left eyes, the respective numbers were 2342 (47.9%), 1667 (34.1%), and 88 (1.8%), for a total of 4097 (83.8%).

Effective response to the cyclopentolate regimen, in at least one eye, was achieved in 4197 children—85.8% of the 4890 examined (Table 3)—ranging from 73.8% in 5-year-olds to 92.1% in 13-year-olds. Response was 86.9% in boys and 84.8% in girls. Among the remaining 683 children in whom cyclople-

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

Visual Acuity Category	Uncorrected Visual Acuity n (%; 95% CI)	Wearing Glasses n (%)*	Presenting Visual Acuity n (%; 95% CI)	Best Visual Activity n (%; 95% CI)
≥20/32 both eyes	4551 (97.3; 96.7–97.9)	7 (0.15)	4555 (97.3; 96.8–97.9)	4625 (98.8; 98.5–99.2)
≥20/32 one eye only	65 (1.39; 1.06–1.72)	0 (0.0)	69 (1.47; 1.16–1.79)	39 (0.83; 0.60–1.07)
≤20/40 to ≥20/63 better eye	38 (0.81; 0.54–1.08)	2 (5.3)	40 (0.85; 0.57–1.14)	11 (0.24; 0.12–0.42)†
≤20/80 to ≥20/160 better eye	20 (0.43; 0.17–0.68)	10 (50.0)	10 (0.21; 0.10–0.39)†	3 (0.06; 0.01–0.19)†
≤20/200 better eye	5 (0.11; 0.03–0.25)†	0 (0.0)	5 (0.11; 0.03–0.25)†	1 (0.02; 0.00–0.12)†
All	4679 (100.0)	19 (2.7)	4679 (100.0)	4679 (100.0)

* Percent of the number within each visual acuity category based on uncorrected vision. One additional child was wearing glasses but without reliable visual acuity measurements.

† Confidence intervals were calculated using the exact binomial distribution instead of the normal approximation. Cluster design effects ranging from 0.847 to 1.291 are not reflected in the confidence intervals for the three exact binomial estimates. Design effects ranging from 0.774 to 1.732 were taken into account in calculating confidence intervals for estimates based on the normal approximation.

TABLE 3. Success of Cycloplegia with Dilation and Availability of Retinoscopy and Autorefraction Measurements in the Examined Population

			Children	
	Right Eyes	Left Eyes	Either Eye	Both Eyes
Examined population	4890 (100.0)	4890 (100.0)	4890 (100.0)	4890 (100.0)
Cycloplegic dilation	4106 (84.0)	4097 (83.8)	4197 (85.8)	4006 (81.9)
Retinoscopy	4048 (82.8)	4027 (82.4)	4142 (84.7)	3957 (80.9)*
Autorefraction	4102 (83.9)	4087 (83.6)	4190 (85.7)	4002 (81.8)†

* Children with retinoscopy in either eye among those with cycloplegic dilation in both eyes; it was used in estimating refractive error prevalence (based on the worse eye). Retinoscopy in both eyes was available for 3933 children.

† This number represents children with autorefraction in either eye among those with cycloplegic dilation in both eyes; it was used in estimating refractive error prevalence (based on the worse eye). Autorefraction in both eyes was available for 3999 children.

gic dilation in neither eye was possible, 73 refused outright the eye drop instillation (mostly young children) or accepted it, but evaluation of cycloplegic response was not possible. Cycloplegic dilation in both eyes was achieved in 4006 (81.9%) children.

Refractive Error

Lack of cooperation, poor fixation, and scissor or unclear reflex in eyes with corneal or media opacities precluded satisfactory retinoscopy measurements in 58 right eyes with cycloplegic dilation, leaving 4048 with such measurements (Table 3). Similarly, retinoscopy measurements were available for 4027 of the 4097 left eyes with cycloplegic dilation. Difficulty was not experienced with autorefraction measurements.

Spherical equivalent (SE) refractive error measured with retinoscopy decreased with age, from a median of +0.75 D in right eyes of 5-year-olds to +0.375 D in 15-year-olds (Fig. 1). Across all ages, the median SE refractive error was +0.625 D in both boys and girls. Mean values were +0.56 ± 0.65 D (SD) in boys and +0.63 ± 0.91 D in girls. With autorefraction, median SE refractive error decreased from +0.75 D in 5-year-olds to +0.50 D in 15-year-olds. Median SE refractive error was

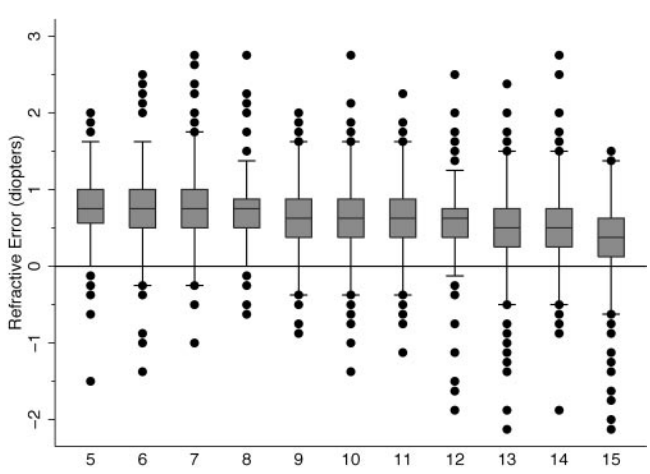

FIGURE 1. Distribution of spherical equivalent refractive error in right eyes by age (years), as measured with cycloplegic retinoscopy. Each *box* extends from the 25th to the 75th percentile of the distribution, the interquartile range, with the bar inside representing the median. *Whiskers* extend to the lower and upper extremes, defined as the 25th percentile minus 1.5 times the interquartile range and the 75th percentile plus 1.5 times the interquartile range. (●) Refractions outside these extremes. Seventeen hyperopic refractions greater than +3.00 D and 21 myopic refractions exceeding −2.25 D are not shown.

+0.625 D in boys and +0.750 D in girls, with mean values +0.59 ± 0.74 D and +0.67 ± 1.04 D, respectively. Findings in left eyes were similar.

The prevalence of hyperopia generally ranged between 1% and 2% when measured with retinoscopy and between 2% and 3% with autorefraction (Table 4). With retinoscopy, the prevalence of myopia did not exceed 3% until age 13, after which a definite upward trend began, reaching 9.0% in 15-year-olds. With autorefraction, myopia was generally approximately 3% or 4%, before rising to 6.3% in 14-year-olds and 9.6% in 15-year-olds.

Myopia with retinoscopy was associated with older age (odds ratio [OR], 1.21; 95% confidence interval [CI], 1.11–1.33) and increased parental education (OR, 1.95; 95% CI, 1.21–3.14). Gender was not significant (P = 0.771). With autorefraction, older age (OR, 1.11; 95% CI, 1.04–1.19) and increased parental education (OR, 1.62; 95% CI, 1.01–2.59) were significant, whereas male gender was of borderline significance (P = 0.077). Statistically significant associations were not found for hyperopia.

Astigmatism of 0.75 D or more was found in 6.7% of right eyes and 6.8% of left eyes, measured with retinoscopy; and in 9.3% and 9.6%, respectively, measured with autorefraction (Table 5). Astigmatism in either eye was present in 9.2% of children with retinoscopy, and in 14.6% with autorefraction. The higher prevalence with autorefraction pertained to both moderate and severe forms of astigmatism. In multiple logistic regression modeling, astigmatism (≥0.75 D) was associated with older age with both retinoscopy (OR, 1.10; 95% CI, 1.05–1.15) and autorefraction (OR, 1.03; 95% CI, 1.00–1.06), but not with gender (P = 0.133 and P = 0.536). For astigmatism greater than 2.00 D, neither age nor gender was significant.

Measurement Agreement

Differences between retinoscopy and autorefraction measurements were dependent on the nature of the underlying refractive error and the child's age. Considering the spectrum of measurements across all ages, autorefraction produced more positive (less negative) readings. The mean difference was +0.049 ± 0.440 D (SD) in right eyes and +0.082 ± 0.451 D in left eyes, with 95% limits of agreement of −0.813 to +0.910 D and −0.801 to +0.965 D, respectively. In young myopes or emmetropes, however, autorefraction was somewhat more negative, but more positive in those with hyperopic refraction. In older age cohorts, autorefraction was more positive across the entire measurement spectrum. None of these systematic differences was of a magnitude sufficient to be clinically meaningful.

TABLE 4. Prevalence of Ametropia by Age in Children with Cycloplegic Dilation in Both Eyes

	Hyperopia*		Myopia†	
Age (y)	Retinoscopy	Autorefraction	Retinoscopy	Autorefraction
5	1.4; 0.0–3.0	2.7; 0.6–4.8	1.9; 0.1–3.7	3.2; 0.6–5.7
6	3.8; 1.6–6.0	2.4; 0.7–4.1	1.6; 0.3–2.9	4.6; 2.4–6.7
7	1.7; 0.4–3.0	2.8; 0.9–4.7	0.6; 0.0–1.4	2.5; 0.8–4.2
8	1.3; 0.0–2.8	1.3; 0.1–2.6	2.4; 0.8–4.0	2.9; 1.2–4.6
9	1.6; 0.2–3.0	2.9; 0.1–5.7	2.1; 0.8–3.4	3.1; 1.4–4.8
10	1.9; 0.7–3.0	3.4; 1.8–4.9	2.5; 1.3–3.8	1.9; 0.6–3.2
11	2.1; 0.7–3.5	3.5; 1.9–5.1	2.8; 1.0–4.6	4.4; 2.8–6.1
12	1.5; 0.4–2.5	3.2; 1.2–5.1	2.5; 0.0–5.1	4.4; 2.2–6.6
13	2.1; 0.9–3.3	2.9; 0.3–5.5	3.4; 1.5–5.4	3.4; 1.7–5.2
14	1.6; 0.3–3.0	1.9; 0.6–3.2	4.6; 2.3–7.0	6.3; 3.6–8.9
15	0.4; 0.0–1.1	0.7; 0.0–1.8	9.0; 5.4–12.5	9.6; 6.4–12.7
All	1.8; 1.4–2.2	2.6; 1.6–3.6	2.9; 2.1–3.8	4.0; 3.3–4.8

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

* Cluster design effects ranged from 0.646 to 1.583 for retinoscopy; and from 0.743 to 1.248 for autorefraction, except for the 13-year age cohort in which it was 2.263.

† Cluster design effects ranged from 0.705 to 1.237 for retinoscopy, except for the 12-year age cohort in which it was 2.743 (accounting for the wide confidence interval); and from 0.658 to 1.123 for autorefraction.

Ocular Abnormalities

Tropia with near fixation was present in 62 (1.3%) of the 4890 examined children, and in 55 (1.1%) with distant fixation. A high proportion of the tropia was esotropia: 71% with near fixation and 64% with distant. Vertical tropia was observed in two children with near fixation and in eight with distant fixation. Exotropia was present in 16 and 12 cases, respectively. With near fixation, 21% of the tropias were 15° or less, 41% were 16° to 30°, and 38% were more than 30°. With distant fixation, the respective percentages were 20%, 41%, and 39%.

Exterior and anterior segment abnormalities were observed in 528 (10.8%) of the 4890 examined children. Eyelid abnormalities were present in 211 eyes of 130 (2.7%) children. Conjunctival abnormalities were present in 291 eyes of 176 (3.6%) children. Corneal abnormalities, mainly scarring, were found in 257 eyes of 235 (4.8%) children. Pupillary abnormalities were noted in 15 eyes of 15 (0.31%) children. Other anterior segment abnormalities were observed in 46 eyes of 35 (0.72%) children.

Media and fundus abnormalities were observed in 96 (2.0%) children: Lenticular abnormalities were present in 56 eyes of 37 (0.76%) children. (One child had aphakia in both eyes, and two children had bilateral pseudophakia; bilateral cortical cataract was present in one child.) Vitreous abnormalities were present in six eyes of four (0.08%) children. Fundus abnormalities (including foveal hypoplasia, optic atrophy, macular scarring, macular holes, cellophane maculopathy, and hereditary macular and retinal degenerations) were present in 85 eyes of 59 (1.2%) children. One child had a prosthetic eye.

Cause of Visual Impairment

Two-thirds of the 128 children with uncorrected visual acuity of 20/40 or worse in at least one eye were affected by refractive error (Table 6). Amblyopia, satisfying explicit criteria,[2] was the cause of impairment in 12 (9.4%) children. Retinal disorders accounted for another 14 (10.9%) children with noncorrectable visual impairment. Reduced vision was unexplained in 23 eyes of 19 (14.8%) children, including 14 children in whom amblyopia was considered the principal cause, even though none of the explicit criteria were met.

Discussion

Nearly 5600 children were enumerated in this survey of urban and semirural school-aged children. Except for a relatively large number of 10-year-olds and a small number of 15-year-olds, the age distribution of the enumerated population was reasonably uniform, as anticipated. The deficit of 15-year-olds may, in part, have been the result of a parent's overstating the age of the child with the intent of avoiding participation in the study. Similarly, 5-year-olds may have been presented as only 4 years of age.

TABLE 5. Prevalence of Astigmatism

	Retinoscopy			Autorefraction		
	Eyes, *n* (%)			Eyes, *n* (%)		
Astigmatism (D)	Right Eyes	Left Eyes	Children* *n* (%)	Right Eyes	Left Eyes	Children* *n* (%)
0.00	1187 (29.3)	1143 (28.4)	714 (18.0)	1193 (29.1)	1236 (30.2)	500 (12.5)
0.25 & 0.50	2590 (64.0)	2609 (64.8)	2880 (72.8)	2528 (61.6)	2458 (60.1)	2916 (72.9)
0.75 to 1.75	237 (5.9)	246 (6.1)	319 (8.1)	338 (8.2)	352 (8.6)	528 (13.2)
≥2.00	34 (0.8)	29 (0.7)	44 (1.1)	43 (1.1)	41 (1.0)	58 (1.4)
All	4048 (100.0)	4027 (100.0)	3957 (100.0)	4102 (100.0)	4087 (100.0)	4002 (100.0)

* Astigmatism in children is categorized using the worse eye.

TABLE 6. Causes of Uncorrected Visual Acuity 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*	Percent Prevalence in the Population One or Both Eyes*
	Right Eyes	Left Eyes		
Refractive error†	59 (65.6)	63 (62.4)	85 (66.4)	1.82
Amblyopia‡	7 (7.8)	7 (6.9)	12 (9.4)	0.26
Corneal opacity	4 (4.4)	3 (3.0)	6 (4.7)	0.13
Cataract\PCO	1 (1.1)	2 (2.0)	3 (2.3)	0.06
Retinal disorder	7 (7.8)	12 (11.9)	14 (10.9)	0.30
Other causes	2 (2.2)	1 (1.1)	2 (1.6)	0.04
Unexplained cause§	10 (11.1)	13 (12.9)	19 (14.8)	0.41
Any cause	90 (100.0)	101 (100.0)	128 (100.0)	2.74

Data are the number with percent in parentheses.

* Children with visual acuity 20/40 or worse in both eyes may represent two different causes of reduced vision—a different cause for each eye. Accordingly, 141 children across all specific causes exceeds the 128 with "any cause" of impairment. Similarly, the total for the cause-specific prevalences exceeds the "any cause" prevalence.

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

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

§ Includes 17 eyes of 14 children in which the examining ophthamologist concluded that amblyopia was the principal cause of impairment, even though the amblyopia criteria were not met.

Given the unreliability of the 1996 census, the attempt to construct clusters within a specific size range manifested significant differences when the enumeration actually took place. Appending geographically adjacent clusters to address the deficit in sample size, rather than using a random selection of additional clusters gave children living in the large, subdivided EAs a greater chance of being included in the survey. However, because the EA structure was merely an accounting framework for the census, there is no reason to suspect that children in these large EAs were in any way different from those in the smaller, undivided ones.

To verify that the discrepancies between census estimates and enumeration data occurred because of deficiencies in census data and not because of misinterpretation of EA/cluster boundaries or inaccurate enumeration, an independent enumeration team repeated the household enumeration in the three clusters with the greatest discrepancies. This repeat enumeration uncovered no problems with the accuracy of cluster boundaries or with the identification of cluster households, confirming the integrity of the enumeration process.

The side effects of cycloplegic dilation impacted negatively on participation in the examination process. With little knowledge or experience regarding the use of cycloplegic agents, both parents and children were intimidated by the fact that children were experiencing blurring of vision and photophobia. (Slight drowsiness, transient fever, and dryness of mouth were also reported.) Without the endorsement of community leaders and the support of local school administrators, participation in examinations would have been even more hesitant.

Although most of the clusters consisted exclusively of children of African origin, two were mainly of Indian origin and one, in a previously white area, was of mixed racial composition. These communities had better access to private eye care and were less willing to subject their children to what were considered unnecessary eye examinations. Nor were they as willing to release the child to the custody of the field team if a parent was unavailable to accompany the child to the examination site. These three clusters contributed disproportionately to the lowering of examination response, with rates of 81.0%, 62.1%, and 51.43%, respectively. One African cluster, also of relatively high socioeconomic status, also had a low response rate (69.2%).

Testing visual acuity in 5-year-olds, and to some extent in 6-year-olds, was problematic, because of poor attention span, lack of understanding, restlessness, and peering. The public school system in South Africa generally admits children after they reach 7 years of age; thus, most 5- and 6-year-olds did not have previous exposure to an instructional environment that would have increased their ability to cooperate with the testing process. Although young children were instructed in advance and led through a practice session outside the examination station, results of visual acuity tests in many 5- and 6-year-olds were unreliable.

Achieving adequate cycloplegia was a general problem, most likely because of the heavily pigmented African eye. Melanin pigment in the iris is a protective chemical barrier that readily absorbs and binds with drugs, and only thereafter releases them slowly in low, nontoxic concentrations.[13] Also, chromatophores in the iris can act as a mechanical blockade, thereby hindering the movement of drug molecules to their intended receptor sites in the ciliary body.[14] The effect of cycloplegic agents may depend also on ethnicity or race itself.[15]

This survey provides reliable evidence that vision impairment is relatively uncommon in school-aged children in South Africa. Only 2.74% of study subjects had uncorrected visual acuity of 20/40 or worse in either eye. This prevalence is much lower than that found in the RESC surveys in Chile,[5] China,[4] or urban India,[7] where the corresponding percentages were 15.8%, 12.8%, and 9.0%, respectively, and more comparable to the 5.0% found in rural India[6] or the 2.9% in rural Nepal.[3]

A distinct upward trend in the prevalence of myopia, beginning around 13 or 14 years of age, was also seen in Chile[5] and India.[6,7] In China[4] the inflection point began earlier, with the 8-year-old cohort. In rural Nepal,[3] there was no apparent trend at any age. Longitudinal follow-up or cross-sectional surveys in older-age cohorts are needed to determine the extent to which the age-related increase in myopia continues beyond 15 years of age[16] and whether the natural history changes with more recent birth cohorts.

The low prevalence of myopia and hyperopia should not be interpreted to suggest that refractive errors are an insignificant contributor to visual disability in South Africa. The gross lack of services in the public sector magnifies their impact, resulting in a significant number of children without appropriate refractive correction. (Only 12 children with significant refractive error were wearing glasses, leaving 51 others, 81%, with the potential to benefit from spectacles.) It has been estimated elsewhere that eye care services in South Africa is appropriately provided for only 20% of the population, whereas 80% lack significant services.[17] The high prevalence of corneal and anterior segment abnormalities found in the study population is a further reflection of the inadequacy of primary eye care services.

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References

1. World Health Organization. *Elimination of Avoidable Visual Disability Due to Refractive Errors.* (WHO/PBL/00.79). Geneva: WHO; 2000.
2. 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.
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. 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.
5. Maul E, Barroso S, Munoz SR, Sperduto RD, Ellwein LB. Refractive error study in children: results from La Florida, Chile. *Am J Ophthalmol*. 2000;129:445–454.
6. Dandona R, Dandona L, Srinivas M,. *et al.* Refractive error study in children in a rural population in India. *Invest Ophthalmol Vis Sci*. 2002;43:615–622.
7. Murthy GVS, Gupta SK, Ellwein L, et al. Refractive error in children in an urban population in New Delhi. *Invest Ophthalmol Vis Sci*. 2002;43:623–631.
8. Ferreira JT. Die rol van optometrie in primere gesondheidsorg. *The South African Optometrist*. 1991;50:175–178.
9. Herse P. An ophthalmic survey of African patients presenting at rural eye clinics in South Africa. *Optom Vis Sci*. 1991;68:738–742.
10. McGregor T. Optometry's strategies for meeting the vision care challenges in the new South Africa. *South African Optometrist*. 1994;53:52–57.
11. Statistics South Africa. The People of South Africa: Population Census 1996, Census in Brief. [Report No. 03-01-11 (1996)]. Pretoria: Statistics South Africa; 1998. (http://www.statssa.gov.za).
12. StataCorp. *Stata Statistical Software: Release 8.0.* College Station, TX: Stata Corporation; 2003.
13. Havener WH. *Ocular Pharmacology.* 4th ed. St.Louis, MO: CV Mosby; 1978:246.
14. Titcomb LC. Mydriatic-cycloplegic and drugs and corticosteroids. *Pharm J*. 1999;263:900–905.
15. Manny RE, Hussein M, Scheiman M. et al. Tropicamide (1%): an effective cycloplegic agent for myopic children. *Invest Ophthalmol Vis Sci*. 2001;42:1728–1735.
16. Zhao J, Mao J, Luo R, Li F, Munoz SR, Ellwein LB. The progression of refractive error in school-age children: Shunyi District, China. *Am J Ophthalmol*. 2002;134:735–743.
17. Pillay YG, Bond P. Health and social policies in the new South Africa. *Int J Health Serv*. 1995;25:727–743.