Prevalence of Refractive Error in Singaporean Chinese Children: The Strabismus, Amblyopia, and Refractive Error in Young Singaporean Children (STARS) Study

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Purpose. To determine the prevalence of refractive error types in Singaporean Chinese children aged 6 to 72 months.

Methods. The Strabismus, Amblyopia and Refractive Error in Singaporean Children (STARS) is a population-based study in southwest Singapore. Door-to-door recruitment of participants was used, with disproportionate random sampling in 6-month increments. Parental questionnaires were administered. Participant eye examinations included logMAR visual acuity, cycloplegic autorefraction, and ocular biometry. Overall and age-specific prevalences of myopia (spherical equivalence [SE] ≤ -0.50 D), high myopia (SE ≤ -6.00 D), hyperopia (SE $\geq +3.00$ D), astigmatism (cylinder $\geq +1.50$ D), and anisometropia (SE difference between each eye ≥ 2.00 D) were calculated.

Results. A total of 3009 children were examined (participation rate, 72.3%). Right eye (OD) cycloplegia data were available for 1375 boys and 1264 girls (mean age, 41 months). Mean OD SE was +0.69 D (SD 1.15). Overall myopia prevalence was 11.0% with no variance between the sexes ($P = 0.91$). The prevalence of high myopia (at least −6.00 D) was 0.2%. The prevalences of hyperopia, astigmatism, and anisometropia were 1.4%, 8.6%, and 0.6%, respectively. Most astigmatism (>95%) was with-the-rule (cylinder axes between 1° and 15° or 165° and 180°). Myopia was present in 15.8%, 14.9%, 20.2%, 8.6%, 7.6%, and 6.4% of children aged 6 to 11, 12 to 23, 24 to 35, 36 to 47, 48 to 59, and 60 to 72 months, respectively. Prevalence increased with age for astigmatism ($P < 0.001$), but not for hyperopia or anisometropia ($P = 0.55$ and $P = 0.37$), respectively.

Conclusions. The prevalences of myopia and astigmatism in young Singaporean Chinese children are high, but that of hyperopia is low. Age effects were observed for each refractive error category, but differences between the sexes were not significant. Age-related variation in myopia prevalence may be influenced by ocular development, environment, and/or testability. (*Invest Ophthalmol Vis Sci.* 2010;51:1348–1355) DOI:10.1167/iovs.09-3587

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Refractive error, and myopia in particular, is one of the five leading causes of visual impairment in the world.[1] It is estimated that, by 2020, approximately one third of the world's population (2.5 billion) will be affected by myopia alone.[2] The prevalence of refractive error in children, particularly before the typical school commencement age of 6 to 7 years, has been assessed in only a limited number of population-based studies. Pediatric studies exploring refractive error have provided useful insights into the early development of refractive error.[3–5]

Studies in Western populations have collectively shown that the prevalence of myopia is low (<5%) in children aged 8 years or younger.[6–11] However, studies in Southeast Asian children suggest a significantly higher prevalence of myopia than that in Western populations. A study of 10,000 Taiwanese school children found that the prevalence of myopia was 6% in 6-year-olds.[12] By comparison, myopia was reported in less than 2% of Australian school students (mean age, 6.7 years),[13] 6.6% of African-American children (age range, 6–72 months), 3.7% of Hispanic children (age range, 6–72 months) (Tarczy-Hornoch K, et al. *IOVS* 2008;49:ARVO E-Abstract 3130), and only 0.7% of Caucasian children (age range, 6–71 months) (Katz J, et al. *IOVS* 2008;49:ARVO E-Abstract 1549).

In this study, we determined the prevalence of refractive error, including myopia, astigmatism, and hyperopia, in a large population-based study of young Singaporean Chinese children aged 6 to 72 months who were recruited through the Strabismus, Amblyopia and Refractive Error in Singaporean Children (STARS) study.

Materials and Methods

Study Population

The STARS study is a population-based study of eye diseases in children aged 6 to 72 months. Eligible participants were recruited from a list of household addresses obtained from the Ministry of Home Affairs of Chinese children aged 6 to 72 months residing in government apart-

ments (where >90% of the population live) in the Southwest region of Singapore, with disproportionate stratified random sampling conducted in 6-month age group increments. Children who had chronic medical or mental conditions and those had not lived at the household address for the past 5 months or who had moved from the resident address were excluded from the STARS study. All children aged 6 to 72 months were invited to participate in the study through mailed invitations, followed by house (door-to-door) visits by trained staff. In total, of the 4162 children invited to participate, 3009 (72.3%) participated. All eye examinations were performed from May 2006 to November 2008 by trained eye professionals, with assessments conducted at two convenient clinic sites within the study area: the Singapore National Eye Center (SNEC) or the Jurong Medical Centre, Singapore. The STARS methodology is similar to that adopted by the Multiethnic Pediatric Eye Disease Study (MEPEDS).[14]

Human subject research approval was obtained from the Institutional Review Boards of the Singapore Eye Research Institute (SERI) and the Singapore National Healthcare Group (NHG), and the study was conducted according to the tenets of the Declaration of Helsinki. Informed written consent was obtained from the parents after a detailed explanation of the study.

Eye Examination

Eye examinations were conducted by trained ophthalmologists, optometrists, and orthoptists and included visual acuity assessment, ocular motility tests (cover testing, ocular movements, stereoacuity, and fixation preference), cycloplegic autorefraction, biometry examination, and fundus photography. Presenting distance visual acuity (VA) measurements were obtained monocularly with a 4-m logarithm of the minimum angle of resolution (logMAR) visual acuity chart (nonilluminated ETDRS chart with Sloan letters) in children aged 30 to 72 months.

Cycloplegic objective refraction was performed with one of three testing methods, which was determined by the child's age and ability to successfully complete the examination. Children aged 24 to 72 months underwent autorefraction (Autorefractor RK-F1; Canon, Tokyo, Japan). For children aged between 12 and 24 months, autorefraction was performed with a hand-held autorefractor (Retinomax K-Plus 2; Nikon, Tokyo, Japan). Five consecutive readings were obtained. Each autorefractor was calibrated daily before testing, and the same two autorefractors were used for all subjects throughout the study. Autorefractor readings were within ≤0.25 D of each other. If the autorefraction test failed or the child was aged 12 months or less, streak retinoscopy (Welch Allyn, Chessy, France) was performed.

Pilot Study Comparing the Three Different Refractive Error Measurements

A pilot study was conducted to compare mean spherical equivalent (SE) measurements between the handheld autorefractor, table-mounted autorefractor, and streak retinoscopy in 51 children (29 boys and 22 girls) aged 24 to 72 months (mean age, 52.3 ± 13.3 months). The measurements were performed by two eye professionals who were masked from the previous refraction test for each participant, and the order of testing was randomized. We found that the mean SE with the table-mounted autorefractor (1.03 D, SD: 1.64) did not differ significantly from that obtained with streak retinoscopy (1.09 D, SD: 1.58; $P = 0.66$). However, the mean SE with the handheld refractor (0.80 D, SD: 1.43) was significantly more minus ($P < 0.001$) than with streak retinoscopy.[15]

Cycloplegic objective refraction was assessed approximately 30 minutes after topical instillation of 3 drops of 1% cyclopentolate (0.5% was used in children aged 12 months or less) and 2.5% phenylephrine, given 5 minutes apart. In 370 (12.3%) children, cycloplegic eye drops were not administered because of parental refusal. Reasons for refusal included the age of the child, concern regarding side effects, unpleasant past experiences, and the child's unwillingness to cooperate. Noncycloplegic refraction measurements were obtained, but are not included in the current analyses.

Axial length (AL), keratometry, and anterior chamber depth (ACD) measurements were obtained monocularly using the noncontact partial coherence interferometer (IOLMaster; Carl Zeiss Meditec, Jena, Germany) in children aged 30 months or older. A total of five consecutive readings were obtained for AL and ACD, with a signal-to-noise ratio >2.0.

Interview

A comprehensive questionnaire was administered to parents by trained interviewers in either the English or Chinese language, and information on demographics, medical history, family eye history, and lifestyle factors was obtained. The average time of completion of the questionnaire was 30 minutes.

Definitions

As the within-subject mean SE of the eyes correlated highly (Spearman correlation coefficient = 0.95, $P < 0.05$), only right eye data are presented. SE was defined as the sphere plus half-negative cylinder. Myopia was defined as SE at least −0.50 D with further subdivision into high myopia (at least −6.00 D). Other definitions of myopia (SE at least −0.75 D and SE at least −1.00 D) and high myopia (SE at least −5.00D) were also used to permit comparison with other epidemiologic studies. Hyperopia was defined as SE of at least +3.00 D. Astigmatism was defined as a cylindrical measurement (all measures were presented in negative notations) of at least 1.50 D and was stratified into three categories: with-the-rule astigmatism (cylinder axes between 1° and 15° or 165° and 180°), against-the-rule-astigmatism (cylinder axes between 75° and 105°), and oblique astigmatism (cylinder axes between 16° and 74° or 106° and 164°).

Statistical Analysis

Age and sex-specific prevalences and 95% confidence intervals were estimated using the Poisson distribution. Clustering within families was accounted for. Appropriate sampling weights were applied to each age stratum for sex-specific and total prevalence. Multivariate logistic regression models with myopia or other refractive error as the dependent variables were constructed to obtain age or sex-adjusted *P*-values (SPSS, ver. 14.0; SPSS Inc., Chicago, IL). Statistical significance was assumed at $P < 0.05$.

Results

A total of 3009 children, including 1570 (52.2%) boys and 1439 (47.8%) girls aged 6 to 72 months were examined. There was no significant difference between the participants ($n = 3009$) and nonparticipants ($n = 1155$ children) by age ($P = 0.98$) or sex ($P = 0.67$; Table 1). However, a significant difference for the study recruitment area was found between participants and nonparticipants ($P < 0.001$), with a greater proportion of participants residing in study areas closer to the clinical examination sites (Table 1). For instance, the study areas with the highest participation rates, Jurong West and South Central, are closest to the examination sites Jurong Medical Centre and Singapore National Eye Centre, respectively. Moreover, of those children who underwent cycloplegia, 1462 (55.4%), 473 (17.9%), and 704 (26.7%) were examined with a table-mounted autorefractor, handheld autorefractor, and streak retinoscopy, respectively.

Of the 3009 children examined, 2639 (87.7%) had cycloplegic refraction measurements, including 1375 (52.1%) boys and 1264 (47.9%) girls and are included in the current analysis. The children whose pupils were dilated were significantly older (mean age, 41 months) compared with those who declined dilation (mean, 37.1 months; $P < 0.001$). The mean SE was also much lower in the nondilated eyes (0.12 D) than in the dilated ones (0.69 D; $P < 0.001$). However, a similar proportion of the boys and girls underwent dilation (boys = 1375, 52.10%, girls = 1264, 47.90%; $P = 0.94$).

The results from the 2639 children who underwent cycloplegic refraction are presented. The mean SE for all the children was 0.69 D (SD 1.15), with no significant difference in

Table 1. Comparisons between Participants and Nonparticipants

	Nonparticipant, *n* (%)	Participant, *n* (%)	*P*
Study area			
Bukit Batok	174 (15.1)	408 (13.6)	
Clementi	121 (10.5)	209 (6.9)	
Jurong East	103 (8.9)	366 (12.2)	
Jurong West	415 (35.9)	1279 (42.5)	
South Central	336 (29.1)	694 (23.1)	
Others	6 (0.6)	53 (1.8)	
			<0.001
Sex			
Male	227 (53.3)	1570 (52.2)	
Female	199 (46.7)	1439 (47.8)	
			0.668
Age group, mo			
6–11.9	62 (5.9)	190 (6.3)	
12–23.9	193 (18.5)	540 (17.9)	
24–35.9	183 (17.5)	516 (17.1)	
36–47.9	194 (18.6)	579 (19.2)	
48–59.9	204 (19.6)	605 (20.1)	
60–72	207 (19.8)	579 (19.2)	
			0.977
Housing and development board apartment			
3-Room	48 (11.6)	70 (6.7)	
4-Room	122 (29.4)	352 (33.8)	
5-Room	201 (48.4)	522 (50.1)	
Executive	44 (10.6)	98 (9.4)	
			0.012

The nonparticipant group has 929 (80.3%) missing sex data, 112 (9.7%) missing age data, and 740 (64.07%) missing apartment data. The participant group has 1967 (65.37%) missing apartment data.

mean SE between the boys (mean SE, 0.65 D, SD: 1.04) and the girls (mean SE, 0.72 D, SD: 1.26; $P = 0.12$; Table 2). A significant age effect for mean SE was reported between the age groups ($P_{trend} = 0.01$), with this finding being consistent in the boys ($P_{trend} = 0.05$), but not in the girls ($P_{trend} = 0.10$). Nonetheless, mean SE was similar across the different age groups, ranging from 0.60 to 0.90 D, with the exception of the children aged 24 to 35.9 months, in whom the mean SE was less hyperopic: 0.38 D (SD: 1.09) in all the children, 0.34 D (SD: 1.02) in the boys, and 0.42 D (SD: 1.17) in the girls. The mean cylindrical power was −0.64 D (SD: 0.66) in all the children and −0.65 D (SD: 0.69) and 0.63 D (SD: 0.63) in the boys and girls, respectively. An age effect for cylindrical power was found in all the children ($P_{trend} < 0.001$), in the boys ($P_{trend} < 0.001$), and in the girls ($P_{trend} < 0.001$; Table 2).

Prevalence of Myopia

The overall adjusted prevalence of myopia (at least −0.50 D) was 11.0% in children aged 6 to 72 months, but decreased to 8.1% and 5.2%, when myopia definitions of at least −0.75 and −1.00 D, respectively, were used (Table 3). Age effects were found for each separate myopia definition ($P < 0.001$), with the younger age groups (<36 months) having a higher prevalence of myopia. For example, the overall myopia prevalence (at least −0.50 D) ranged from 6.4% to 8.6% in the children aged 36 to 72 months, but was 15.8%, 14.9%, and 20.2%, in children aged 6 to 11.9, 12 to 23.9, and 24 to 35.9 months, respectively (Table 3). This trend was also observed when the boys and girls were analyzed separately. Moreover, the boys (11.3%) and girls (11.5%) had a similar overall prevalence of myopia ($P = 0.91$). Furthermore, considering that we found that the Retinomax autorefractor (Nikon) may in part explain the inflated prevalence of myopia in the younger age group (24–35.0 months), we have also provided a table describing the prevalence without the use of that autorefractor (Table 4).

The overall adjusted prevalence of high myopia defined as either ≤ −5.00 D or ≤ −6.00 D was 0.39% and 0.24%, respectively, with no age effect found for each definition ($P = 0.55$ and $P = 0.24$; Table 3). There was also no significant difference in the

Table 2. Distribution of Refractive Error in Right Eyes of the Participants

Age Ranges (mo)	*N*	SE (D)							Cylinder (D)						
		Mean	SD	Median	Range	K	S	K-S	Mean	SD	Median	Range	K	S	K-S
All children	2639	0.69	1.15	0.75	22.2	27.6	−2.5	<0.001	−0.64	0.66	−0.5	7.5	14.1	−2.8	<0.001
6–11.9	165	0.85	1.16	1.00	8.25	3.34	−0.98	0.001	−0.38	0.55	0.000	3.50	6.73	−2.12	<0.001
12–23.9	450	0.70	1.06	0.75	9.38	5.28	−1.12	<0.001	−0.41	0.47	−0.50	4.0	7.12	−1.77	<0.001
24–35.9	441	0.38	1.09	0.43	7.60	0.56	−0.09	0.660	−0.67	0.57	−0.53	4.2	9.76	−2.41	<0.001
36–47.9	513	0.61	1.14	0.73	13.47	24.53	−3.37	<0.001	−0.74	0.71	−0.55	7.5	23.2	−3.62	<0.001
48–59.9	540	0.82	1.38	0.88	22.20	48.83	−3.98	<0.001	−0.75	0.77	−0.55	6.8	12.2	−2.80	<0.001
60–72	530	0.81	0.97	0.90	14.08	23.82	−2.57	<0.001	−0.70	0.68	−0.50	4.9	6.44	−2.23	<0.001
P_{trend}					0.010							<0.001			
Boys	1375	0.65	1.04	0.75	14.8	12.2	−1.33	<0.001	−0.65	0.69	−0.50	7.5	14.1	−2.77	<0.001
6–11.9	78	0.83	1.09	1.00	6.75	1.48	−0.16	0.022	−0.34	0.60	0.00	3.5	10.2	−2.75	<0.001
12–23.9	256	0.63	1.01	0.75	9.38	6.06	−1.21	0.001	−0.37	0.43	−0.36	2.0	0.78	−1.06	<0.001
24–35.9	222	0.34	1.02	0.38	6.73	0.82	0.28	0.642	−0.68	0.60	−0.50	4.1	9.15	−2.39	<0.001
36–47.9	267	0.65	0.89	0.70	8.08	7.58	−1.39	0.282	−0.77	0.79	−0.60	7.5	24.9	−3.91	<0.001
48–59.9	284	0.75	1.18	0.78	14.2	14.9	−1.16	0.002	−0.80	0.77	−0.60	5.5	6.47	−2.14	<0.001
60–72	268	0.75	1.02	0.90	12.4	32.6	−3.75	0.004	−0.71	0.69	−0.50	4.9	7.0	−2.27	<0.001
P_{trend}					0.049							<0.001			
Girls	1264	0.72	1.26	0.83	21.8	34.3	−3.24	<0.001	−0.63	0.63	−0.50	6.8	13.8	−2.78	<0.001
6–11.9	87	0.86	1.22	1.00	7.0	4.6	−1.5	0.060	−0.41	0.50	−0.25	2.0	1.5	−1.26	<0.001
12–23.9	194	0.80	1.12	1.00	9.0	4.76	−1.10	0.004	−0.46	0.53	−0.50	4.0	10.1	−2.21	<0.001
24–35.9	219	0.42	1.17	0.47	6.7	0.40	−0.37	0.830	−0.66	0.55	−0.55	4.2	10.6	−2.42	<0.001
36–47.9	246	0.57	1.36	0.73	13.5	23.3	−3.71	<0.001	−0.70	0.60	−0.55	4.5	9.2	−2.46	<0.001
48–59.9	256	0.89	1.57	0.98	21.8	57.5	−5.24	<0.001	−0.69	0.76	−0.55	6.8	20.2	−3.63	<0.001
60–72	262	0.86	0.93	0.90	10.7	10.5	−1.01	0.013	−0.68	0.66	−0.50	4.0	5.83	−2.20	<0.001
P_{trend}					0.097							<0.001			

n, sample size; K, kurtosis; S, skewness.

TABLE 3. Prevalence Rates of Myopia and High Myopia

Age Range (mo)	*N*	Myopia (SE at Least −0.5 D) *n* (%, 95% CI)	Myopia (SE at Least −0.75 D) *n* (%, 95% CI)	Myopia (SE at Least −1.0 D) *n* (%, 95% CI)	High Myopia (SE at Least −5.0 D) *n* (%, 95% CI)	High Myopia (SE at Least −6.0 D) *n* (%, 95% CI)
All children						
Crude rate	2639	301 (11.4, 10.2–12.7)	219 (8.3, 7.3–9.4)	140 (5.3, 4.5–6.2)	10 (0.38, 0.18–0.70)	6 (0.22, 0.08–0.50)
Adjusted rate*		301 (11.0, 10.9–11.2)	219 (8.1, 8.0–8.2)	140 (5.2, 5.1–5.3)	10 (0.39, 0.36–0.42)	6 (0.24, 0.22–0.26)
6–11.9	165	26 (15.8, 10.6–22.2)	16 (9.7, 5.6–15.3)	8 (4.8, 2.1–9.3)	0 (0.0, 0.0–2.2)	0 (0.0, 0.0–2.2)
12–23.9	450	67 (14.9, 11.7–18.5)	53 (11.8, 8.9–15.1)	29 (6.4, 4.3–9.1)	2 (0.44, 0.05–1.6)	0 (0.0, 0.0–0.8)
24–35.9	441	89 (20.2, 16.5–24.2)	68 (15.4, 12.2–19.1)	45 (10.2, 7.5–13.4)	0 (0.0, 0.0–0.8)	0 (0.0, 0.0–0.8)
36–47.9	513	44 (8.6, 6.3–11.3)	30 (5.8, 4.0–8.2)	24 (4.7, 3.0–6.9)	4 (0.78, 0.21–2.0)	3 (0.58, 0.12–1.7)
48–59.9	540	41 (7.6, 5.5–10.1)	27 (5.0, 3.3–7.2)	21 (3.9, 2.4–5.9)	2 (0.37, 0.04–1.3)	2 (0.37, 0.04–1.3)
60–72	530	34 (6.4, 4.5–8.8)	25 (4.7, 3.1–6.9)	13 (2.5, 1.3–4.2)	2 (0.38, 0.05–1.3)	1 (0.19, 0.005–1.0)
P_{trend}		<0.001	<0.001	<0.001	0.55	0.24
Boys	1375	156 (11.3, 9.7–13.1)	109 (7.9, 6.6–9.5)	69 (5.0, 3.9–6.3)	4 (0.29, 0.08–0.7)	2 (0.15, 0.02–0.5)
6–11.9	78	14 (17.9, 10.2–28.3)	7 (9.0, 3.7–17.6)	5 (6.4, 2.1–14.3)	0 (0.0, 0.0–0.05)	0 (0.0, 0.0–0.4.6)
12–23.9	256	39 (15.2, 11.1–20.2)	29 (11.3, 7.7–15.9)	18 (7.0, 4.2–10.9)	1 (0.39, 0.01–2.1)	0 (0.0, 0.0–1.4)
24–35.9	222	43 (19.4, 14.4–25.2)	33 (14.9, 10.5–20.2)	19 (8.6, 5.2–13.0)	0 (0.0, 0.0–1.6)	0 (0.0, 0.0–1.6)
36–47.9	267	19 (7.1, 4.3–10.9)	13 (4.9, 2.6–8.2)	10 (3.7, 1.8–6.8)	1 (0.37, 0.01–2.1)	0 (0.0, 0.0–1.4)
48–59.9	284	22 (7.7, 4.9–11.5)	15 (5.3, 3.0–8.6)	10 (3.5, 1.7–6.4)	1 (0.35, 0.01–1.9)	1 (0.35, 0.01–1.9)
60–72	268	19 (7.1, 4.3–10.9)	12 (4.5, 2.3–7.7)	7 (2.6, 1.1–5.3)	1 (0.37, 0.01–2.1)	1 (0.37, 0.01–2.1)
P_{trend}		<0.001	<0.001	0.002	0.64	0.22
Girls	1264	145 (11.5, 9.8–13.3)	110 (8.7, 7.2–10.4)	71 (5.6, 4.4–7.0)	6 (0.47, 0.17–1.0)	4 (0.32, 0.09–0.81)
6–11.9	87	12 (13.8, 7.3–22.8)	9 (10.3, 4.8–18.7)	3 (3.4, 0.7–9.7)	0 (0.0, 0.0–4.1)	0 (0.0, 0.0–4.1)
12–23.9	194	28 (14.4, 9.8–20.2)	24 (12.4, 8.1–17.8)	11 (5.7, 2.9–9.9)	1 (0.51, 0.01–2.8)	0 (0.0, 0.0–1.9)
24–35.9	219	46 (21.0, 15.8–27.0)	35 (16.0, 11.4–21.5)	26 (11.9, 7.9–16.9)	0 (0.0, 0.0–1.7)	0 (0.0, 0.0–1.7)
36–47.9	246	25 (10.2, 6.7–14.6)	17 (6.9, 4.1–10.8)	14 (5.7, 3.1–9.4)	3 (1.2, 0.25–3.5)	3 (1.2, 0.25–3.5)
48–59.9	256	19 (7.4, 4.5–11.3)	12 (4.6, 2.4–8.0)	11 (4.3, 2.2–7.6)	1 (0.39, 0.01–2.2)	1 (0.39, 0.01–2.2)
60–72	262	15 (5.7, 3.2–9.3)	13 (5.0, 2.7–8.3)	6 (2.3, 0.8–4.9)	1 (0.38, 0.01–2.1)	0 (0.0, 0.0–1.4)
P_{trend}		<0.001	<0.001	0.025	0.71	0.68

* Adjusted to the 2000 Singapore population census; accounting for clustering in families and age sampling.

prevalence of high myopia (at least −6.00 D) between the boys (0.15%) and girls (0.32%; $P = 0.37$; Table 3). Because of the variation in myopia prevalence among the various age groups, we stratified our sample into two principal age groups. The myopia prevalence was 15.1% and 10.3% in the children aged 6 to 23.9 months and 24 to 72 months, respectively, $P = 0.001$. No significant difference ($P = 0.20$) was found in the prevalence of high myopia in these age groups (0% and 0.3%, respectively).

Prevalences of Hyperopia and Anisometropia

The overall adjusted prevalence of hyperopia (at least +3.00 D) for all the children was 1.35%, with the prevalence increasing to 7.8% with a definition of at least +2.00 D (Table 5). Considering the young age of our participants, the former definition is more conservative and is preferred. No age effect was found for the prevalence of hyperopia between all the age groups ($P = 0.55$) or when the boys and girls were analyzed separately ($P = 0.55$ and $P = 0.75$, respectively; Table 5). The boys (1.0%) and girls (1.8%) were found to have a similar overall prevalence of hyperopia ($P = 0.10$). Moreover, the overall adjusted prevalence of anisometropia (difference of at least 2.00 D) was 0.60%, with no age effects found for all the children ($P = 0.73$) or for the boys ($P = 0.51$) and girls ($P = 0.53$) separately. There was also no significant difference in the prevalence of anisometropia between the boys (0.9%) and girls (0.47%; $P = 0.54$; Table 5).

TABLE 4. Prevalence of Myopia without the Autorefractor

Age (mo)	*n* (Prevalence %, 95% CI) (without autorefractor)	*n* (Overall Prevalence %, 95% CI)
6–11.9	160 (16.3, 10.5–22.0)	26 (15.8, 10.6–22.2)
12–23.9	384 (12.0, 8.7–15.2)	67 (14.9, 11.7–18.5)
24–35.9	213 (9.9, 5.9–13.9)	89 (20.2, 16.5–24.2)
36–47.9	387 (5.9, 3.6–8.3)	44 (8.6, 6.3–11.3)
48–59.9	504 (6.4, 4.2–8.5)	41 (7.6, 5.5–10.1)
60–72	511 (6.1, 4.0–8.1)	34 (6.4, 4.5–8.8)
Total	2159	2639

Prevalence of Astigmatism

The overall adjusted prevalence of astigmatism (at least 1.50 D) was 8.6% (95% CI: 8.5%–8.7%), with the prevalence increasing with age ($P < 0.001$; Table 5). For example, the prevalence of astigmatism in the children aged 60 to 72 months was 11.3%, compared with only 3.6% in the children aged 12 to 23.9 months (Table 5). The overall prevalence of astigmatism between the boys (9.2%) and girls (7.3%) was similar ($P = 0.10$), with an age-related increase in the prevalence evident for both the boys ($P < 0.001$) and girls ($P = 0.005$; Table 5). Prevalence estimates for with-the-rule astigmatism, against-the-rule astigmatism, and oblique astigmatism were 6.91%, 0.19%, and 0.83%, respectively (Table 5). A significant age effect was found only for with-the-rule astigmatism ($P < 0.001$; Table 5).

DISCUSSION

This population-based survey of eye diseases in Asian preschool children aged 6 to 72 months reports the prevalence of refractive error, including myopia, astigmatism, and hyperopia. We found that the overall prevalences of myopia (at least −1.00 D) and astigmatism (at least 1.50 D) were high in our sample of Singaporean Chinese children, 5.2% and 8.6%, respectively, with a relatively low prevalence of hyperopia (at least +3.00 D, 1.4%).

TABLE 5. Prevalences of Astigmatism, Hyperopia, and Anisometropia

Age Range (mo)	*n*	Astigmatism (Cylinder at Least 1.5 D) *n* (%, 95% CI)	With-the-Rule Astigmatism *n* (%, 95% CI)	Against-the-Rule Astigmatism *n* (%, 95% CI)	Oblique Astigmatism *n* (%, 95% CI)	Hyperopia (SE at Least +2.0 D) *n* (%, 95% CI)	Hyperopia (SE at Least +3.0 D) *n* (%, 95% CI)	Anisometropia (Difference of at Least −2.0 D) *n* (%, 95% CI)
All children								
Crude rate	2639	220 (8.3, 7.3–9.5)	177 (6.71, 5.78–7.73)	5 (0.19, 0.06–0.44)	21 (0.80, 0.49–1.21)	206 (7.8, 6.8–8.8)	37 (1.4, 0.95–1.9)	15 (0.57, 0.32–0.93)
Adjusted rate*		220 (8.6, 8.5–8.7)	177 (6.91, 6.79–7.03)	5 (0.19, 0.17–0.21)	21 (0.83, 0.79–0.87)	206 (7.5, 7.4–7.6)	37 (1.35, 1.29–1.41)	15 (0.6, 0.56–0.64)
6–11.9	165	9 (5.5, 2.5–10.1)	9 (5.45, 1.95–8.96)	0 (0.0, 0.0–1.80)	0 (0.0, 0.0–1.80)	26 (15.7, 10.6–22.2)	5 (3.0, 1.0–6.9)	0 (0.0, 0.0–2.2)
12–23.9	450	16 (3.6, 2.0–5.7)	13 (2.89, 1.33–4.44)	1 (0.22, 0.0–0.66)	2 (0.44, 0.0–1.06)	46 (10.2, 7.6–13.4)	7 (1.6, 0.63–3.2)	1 (0.22, 0.01–1.2)
24–35.9	441	33 (7.5, 5.2–10.3)	19 (4.31, 2.40–6.21)	4 (0.91, 0.02–1.80)	3 (0.68, 0.0–1.45)	30 (6.8, 4.6–9.6)	4 (0.91, 0.25–2.3)	2 (0.45, 0.01–1.6)
36–47.9	513	42 (8.2, 6.0–10.9)	36 (7.02, 4.80–9.23)	0 (0.0, 0.0–0.58)	5 (0.97, 0.12–1.83)	26 (5.1, 3.3–7.3)	2 (0.39, 0.05–1.4)	6 (1.2, 0.43–2.5)
48–59.9	540	60 (11.1, 8.6–14.1)	48 (8.89, 6.48–11.30)	0 (0.0, 0.0–0.55)	8 (1.48, 0.0–2.50)	48 (8.9, 6.6–11.6)	14 (2.6, 1.4–4.3)	4 (0.74, 0.20–1.9)
60–72	530	60 (11.3, 8.7–14.3)	52 (9.81 7.27–12.35)	0 (0.0, 0.0–0.56)	3 (0.57, 0.0–1.21)	30 (5.7, 3.8–8.0)	5 (0.94, 0.31–2.2)	2 (0.38, 0.05–1.3)
P_{trend}		<0.001	<0.001	0.13	0.21	0.001	0.55	0.37
Boys (All)	1375	127 (9.2, 7.7–10.9)	105 (7.64, 6.23–9.04)	2 (0.15, 0.0–0.35)	11 (0.80, 0.33–1.27)	87 (6.3, 5.1–7.7)	14 (1.0, 0.55–1.7)	9 (0.65, 0.30–1.2)
6–11.9	78	5 (6.4, 2.1–14.3)	5 (6.41 2.11–14.33)	0 (0.0, 0.0–3.77)	0 (0.0, 0.0–3.77)	9 (11.5, 5.4–20.8)	2 (2.6, 0.31–9.0)	0 (0.0, 0.0–4.6)
12–23.9	256	7 (2.7, 1.1–5.6)	6 (2.34 0.86–5.03)	0 (0.0, 0.0–1.16)	1 (0.39, 0.01–2.16)	23 (9.0, 5.8–13.2)	2 (0.78, 0.09–2.8)	1 (0.39, 0.01–2.2)
24–35.9	222	19 (8.6, 5.2–13.0)	12 (5.41, 2.82–9.25)	2 (0.90, 0.11–3.21)	0 (0.0, 0.0–1.34)	13 (5.9, 3.1–9.8)	3 (1.4, 0.28–3.9)	1 (0.45, 0.01–2.5)
36–47.9	267	25 (9.4, 6.2–13.5)	22 (8.24, 5.23–12.21)	0 (0.0, 0.0–1.12)	3 (1.12, 0.23–3.25)	12 (4.5, 2.3–7.7)	0 (0.0, 0.0–1.4)	3 (1.1, 0.23–3.2)
48–59.9	284	38 (13.4, 9.6–17.9)	30 (10.56, 7.24–14.74)	0 (0.0, 0.0–1.05)	6 (2.11, 0.78–4.54)	17 (6.0, 3.5–9.4)	6 (2.1, 0.78–4.5)	3 (1.1, 0.22–3.1)
60–72	268	33 (12.3, 8.6–16.9)	30 (11.19, 7.68–15.59)	0 (0.0, 0.0–1.11)	1 (0.37, 0.01–2.06)	13 (4.9, 2.6–8.2)	1 (0.37, 0.01–2.1)	1 (0.37, 0.01–2.1)
P_{trend}		<0.001	<0.001	0.43	0.17	0.017	0.55	0.52
Girls (all)	1264	93 (7.3, 6.0–8.9)	72 (5.70 4.42–6.98)	3 (0.24, 0.0–0.51)	10 (0.79, 0.30–1.28)	119 (9.4, 7.9–11.1)	23 (1.8, 1.1–2.7)	6 (0.47, 0.17–1.0)
6–11.9	87	4 (4.6, 1.3–11.3)	4 (4.60 1.27–11.36)	0 (0.0, 0.0–3.39)	0 (0.0, 0.0–3.39)	17 (19.5, 11.8–29.4)	3 (3.4, 0.72–9.7)	0 (0.0, 0.0–4.2)
12–23.9	194	9 (4.6, 2.1–8.6)	7 (3.61, 1.46–7.29)	1 (0.52, 0.01–2.84)	1 (0.51, 0.01–2.84)	23 (11.9, 7.7–17.3)	5 (2.6, 0.84–5.9)	0 (0.0, 0.0–1.9)
24–35.9	219	14 (6.4, 3.5–10.5)	7 (3.20 1.29–6.47)	2 (0.91, 0.11–3.26)	3 (1.37, 0.28–3.95)	17 (7.8, 4.6–12.1)	1 (0.46, 0.01–2.5)	1 (0.46, 0.01–2.5)
36–47.9	246	17 (6.9, 4.1–10.8)	14 (5.69 3.15–9.36)	0 (0.0, 0.0–1.21)	2 (0.81, 0.10–2.91)	14 (5.7, 3.1–9.4)	2 (0.81, 0.10–2.9)	3 (1.2, 0.25–3.5)
48–59.9	256	22 (8.6, 5.5–12.7)	18 (7.03 4.22–10.88)	0 (0.0, 0.0–1.16)	2 (0.78, 0.09–2.79)	31 (12.1, 8.4–16.7)	8 (3.1, 1.3–6.1)	1 (0.39, 0.01–2.1)
60–72	262	27 (10.3, 6.9–14.6)	22 (8.40 5.34–12.44)	0 (0.0, 0.0–1.14)	2 (0.76, 0.09–2.73)	17 (6.5, 3.8–10.2)	4 (1.5, 0.41–3.9)	1 (0.38, 0.01–2.1)
P_{trend}		0.005	0.009	0.19	0.73	0.013	0.75	0.53

* The 2000 Singapore census population, accounting for clustering in families and age sampling.

Our study findings, particularly the prevalence of refractive error, cannot be directly compared to the results in another recent population-based study that explored refractive error in young children, the MEPEDS (Tarczy-Hornoch K, et al. *IOVS* 2008;49:ARVO E-Abstract 3130). In that study, myopia (at least −1.00 D) was found in 6.6% of African-American children (n = 2993) and in 3.7% of Hispanic children (n = 3024), with no significant difference between the sexes for each ethnic group. The BPEDS (Baltimore Pediatric Eye Disease Study; Katz J, et al. *IOVS* 2008;49:ARVO E-Abstract 1549) found a similar prevalence of myopia (at least −1.00 D) in African-American children (5.5%) and reported a prevalence of only 0.7% in Caucasian children. Although large components of our study methodology are similar to those of the MEPEDS and BPEDS, there are minor but important differences in our approaches to measuring refractive error. With the knowledge gained from our pilot study, which showed that the Retinomax autorefractor (Nikon) overestimated the myopic component of refraction in young children,[16] we decided on the table-mounted autorefractor as the primary method of measuring refractive error in the children aged 24 months or older, as this instrument has been shown to be more reliable.[17] The Retinomax was used in both the MEPEDS and BPEDS in their main refractive test, and retinoscopy was performed only if that test failed or if cycloplegia was refused. In our study, refractive measurements obtained from the Retinomax represented less than 20% of cases. Nonetheless, we found that the prevalence of myopia (at least −0.75 D) in our study (ages 5–6 years) was similar (4.7%) to that reported in the Refractive Error Study in Children (RESC) study (5.7% with stand-alone autorefraction) in 5-year-old children residing in South China.[18] The prevalence of myopia in our study is similar to that in a study of 260 Taiwanese school children (5.8% in 7-year-olds),[12] but much higher than that reported in 1742 Australian school students (<2% in children with a mean age of 6.7 years).[13] No further comparisons could be made with the results of other studies, as they included children of older ages.

We did not observe an age-related increase in myopia prevalence. However, data already reported from a population-based Singapore eye study conducted in school-aged children and teenagers demonstrated that the prevalence of myopia increased from 29% at age 7 years, to 35% by age 8 years, and to 43% by age 9 years.[19] Both our study and the MEPEDS (Tarczy-Hornoch K, et al. *IOVS* 2008;49:ARVO E-Abstract 3130) found a higher prevalence of myopia in younger children aged 24 months or less. In our study, the higher prevalence of myopia was still observed when the age groups were divided into two groups, with the younger group (6–23.9 months) still having a significantly higher prevalence (15.2%) than the older group (24–72 months, 10.3%; P = 0.001). One possible reason is that the process of emmetropization may take place as early as the first few years of life. However, it could also be argued that refractive error in children below 24 months is both difficult to measure and often overestimated. In addition, complete cycloplegia may be more difficult to achieve in young children, with residual accommodative facility affecting the overall refractive error findings.

Previous studies exploring the prevalences of hyperopia and astigmatism in young children have also shown marked variation in prevalence levels.[18,20–26] For example, the prevalence of astigmatism (≥1.00 D) was reported to be 19.2% in 1,028 Singaporean children aged 7 to 9 years[27] and 14.6% in more than 10,000 Taiwanese children[28] (7–18 years), compared with only 4.8% in 1,765 Australian children aged 6 years.[29] Moreover, the prevalence of hyperopia has been reported to range from less than 1% to as high as 26% in children aged 5 to 15 years.[18,20–26] A more recent study reported a hyperopia prevalence in 6- and 12-year-old Australian children of 13.2% and 5.0%, respectively.[30]

The prevalence of hyperopia has been reported to range from less than 1% to as high as 26% in children aged 5 to 15 years.[18,20–26] In our study, 7.5% of children were hyperopic (defined as at least 2.0 D), with the prevalence decreasing with age. This is similar to a recent study reporting a 5.0% prevalence of hyperopia in a multiethnic population of 6-year-old Australian children.[30] In contrast, the MEPEDS (Tarczy-Hornoch K, et al. *IOVS* 2008;49:ARVO E-Abstract 3130) reported a much higher prevalence of hyperopia (greater than 20%, with the Retinomax; Nikon), predominantly for examinations of both African-American and Hispanic children, with no reported age effects. The BPEDS (Katz J, et al. *IOVS* 2008;49:ARVO E-Abstract 1549) also found that 8.9% of the white children and 4.4% of the African-American children had hyperopia of at least 3.0 D, whereas only 1.4% of our Singaporean Chinese children were hyperopic according to this definition. Irrespective of the definitions used, it is evident that Singaporean Chinese children have a substantially lower prevalence of hyperopia than do Western children, which could reflect trends for earlier development of myopia in Singaporean Chinese children.

The prevalence of astigmatism has varied among different ethnic groups and sample populations, with the prevalence ranging from 3.8% to as high as approximately 50% in children aged between 2 and 19 years.[18,24,27–29,31–35] This large variation may be explained by the use of various refractive definitions of astigmatism, small sample size, testing methodology, ethnicity, response rates, and differences in the age cohorts assessed. Very few population-based studies have assessed astigmatism in children aged less than 6 years. Nonetheless, the prevalence of astigmatism (at least 1.50 D) in our study was 8.6% and was found to increase with age. This finding was significantly lower than the astigmatism prevalence reported in Hispanic and African-American children for all age groups in the MEPEDS (Tarczy-Hornoch K, et al. *IOVS* 2008;49:ARVO E-Abstract 3130) with the Retinomax (Nikon). Moreover, contrary to our findings, MEPEDS showed a trend toward decreasing prevalence with age ($P < 0.0001$, trend test). Our prevalence (11.3% in children aged 60–72 months) was more consistent with findings from an Australian study that examined 1765 children aged 6 years of age from various races and reported a 10.3% astigmatism prevalence (at least 0.75 D, measured by a table-mounted autorefractor). Our study findings also correspond to those reported in children from India (5.9%),[31] Southern India (8.7%),[36] and urban China (6.8%), when the same 0.75 D (autorefractor) astigmatism cutoff was used.[33] Furthermore, the prevalence of astigmatism would be expected to increase further with age, as in the SCORM study, which reported a prevalence of refractive astigmatism as high as 19.2% in older Singaporean children (aged 7–9 years).[27]

The STARS study was undertaken on a large representative sample of young Singaporean Chinese children who resided in the Southwest regions of Singapore. We used several approaches to optimize our participation rate, including door-to-door home visits, invitation letters, reminder letters, and many telephone reminder calls. We also provided several examination sites and allowed for appointment preference, including weekday and weekend appointments, as well as ensuring that all participants who failed to attend were followed up and provided with alternate appointment times. Our participation rate (72.3%) was higher compared with that in the BPEDS (62%),[37] and moderately lower than that achieved in the MEPEDS (78%).[14] Furthermore, we used the more accurate standalone autorefractor to assess refractive error in older children.

Several limitations of the STARS must be addressed—namely, the differences between the participants and nonparticipants, the number of who refused dilation, the testability of refraction for certain age groups, the lack of ethnic comparison, and the use of different refractive tests. A greater number

of participants came from study areas closer in proximity to the clinical sites and from apartments with more rooms compared with those of nonparticipants, which may have led to a selection bias and either an over- or underestimation of refractive error prevalence. Although all parents were provided with verbal and written information on the use and benefits of cycloplegia in determining children's refractive status, we still had more than 10% who refused to have their children undergo pupil dilation. Moreover, with the very young age range, three different tests for refraction measurements were needed, with autorefraction being less testable in the younger age groups (between 12 and 30 months). In addition, despite having less than one fifth of the subjects undergo handheld Retinomax (Nikon) testing, there is still a need to evaluate its comparability to table-mounted autorefraction and streak retinoscopy, which were used in the older and younger age brackets, respectively. This refractometer has been shown to overestimate negative refraction,[17] and thus could have contributed to a higher myopia prevalence (10.2%), particularly in children aged 24 to 35.9 months. Moreover, the use of the Retinomax is of particular concern, considering the high proportion of children being assessed with it in only one defined age group.

There is mounting evidence to suggest that the prevalence of myopia is substantially higher in urban Asian populations such as Singapore, Hong Kong, and Taiwan compared with that in Western populations.[38] These differences have been attributed primarily to environmental differences—namely, excessive amounts of near work, educational attainment, socioeconomic status, and more recently the level of outdoor activity. Of interest, in our study a higher prevalence of myopia was also found in Singaporean Chinese children early in life. Most Singaporean children attend 3 years of kindergarten and actively participate in extra tuition and computer classes from ages as early as 3 to 4 years. However, genes and gene–environment interaction may play a substantial role in the development of myopia in very young Singaporean children who may not yet have been exposed to the intensive elementary schooling system that commences at age 6 years.

In conclusion, in our sample of young Singaporean Chinese children, we found relatively high overall prevalences of myopia and astigmatism that varied by age, but not by sex. However, the prevalence of hyperopia was low, with significant variation by age and sex.

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