Prevalence of Hyperopia and Associations with Eye Findings in 6- and 12-Year-Olds

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Purpose: To describe the prevalence of hyperopia and associated factors in a representative sample of Australian schoolchildren 6 and 12 years old.

Design: Population-based cross-sectional study.

Participants: Schoolchildren ages 6 (n = 1765) and 12 (n = 2353) from 55 randomly selected schools across Sydney.

Methods: Detailed eye examinations included cycloplegic autorefraction, ocular biometry, cover testing, and dilated fundus examination. Information on birth and medical history were obtained from a parent questionnaire.

Main Outcome Measures: Moderate hyperopia defined as spherical equivalent (SE) refraction of ≥+2.00 diopters (D), and eye conditions including amblyopia, strabismus, astigmatism, and anisometropia.

Results: Prevalences of moderate hyperopia among children ages 6 and 12 were 13.2% and 5.0%, respectively; it was more frequent in children of Caucasian ethnicity (15.7% and 6.8%, respectively) than in children of other ethnic groups. Compared with children without significant ametropia (−0.49 ≤ SE refraction ≤ +1.99 D), the prevalence of eye conditions including amblyopia, strabismus, abnormal convergence, and reduced stereoacuity was significantly greater in children with moderate hyperopia (all *P*s < 0.01). Maternal smoking was significantly associated with moderate hyperopia among 6-year-olds (*P* = 0.03), but this association was borderline among 12-year-olds (*P* = 0.055). Early gestational age (<37 weeks) and low birth weight (<2500 g) were not statistically significant predictors of moderate hyperopia in childhood.

Conclusions: Moderate hyperopia was strongly associated with many common eye conditions, particularly amblyopia and strabismus, in older children. Birth parameters did not predict moderate hyperopia. *Ophthalmology 2008;115:678–685 © 2008 by the American Academy of Ophthalmology.*

Hyperopia is the usual refractive state among young children. Most neonates and infants are hyperopic,[1,2] and at least 95% of infants have a hyperopic refraction up to +3.50 diopters (D).[3] The reported prevalence rates for hyperopia in schoolchildren vary widely among countries, ranging from 0.6% to 26%, based on a spherical equivalent (SE) refraction definition of >+2.00 D (Table 1 [available at http://aaojournal.org]).[4–11] Few studies of refractive error in European Caucasian childhood populations have been focused on hyperopia, with some studies limited by relatively small[12] or non–population based samples.[13,14] Two previous studies[15,16] reported the prevalence of hyperopia in Australian children, but only one study employed cycloplegia.[16]

Although the prevalence of hyperopia falls in older schoolchildren,[4–11] its persistence beyond the first year of life is associated with a markedly greater risk of visual deficit.[17,18] Increasing evidence also suggests an association with poorer school performance[19–21] and a range of developmental deficits.[22] For children with moderately hyperopic refraction, a strong association with strabismus[23,24] and amblyopia[24–27] has been reported. Currently, there are very few data in the literature on risk factors for this common eye condition.[2,28]

In this study of 2 randomly selected cluster samples of Australian children (predominantly 6 and 12 years old), we aimed to determine the prevalence of and associations with hyperopia, including ocular biometric parameters and the frequency of other common coexisting eye conditions.

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Materials and Methods

Study Population

The Sydney Myopia Study is a population-based survey of eye health in children enrolled in schools in the Sydney metropolitan area, Australia. The project forms part of the Sydney Childhood Eye Study, which is examining childhood eye conditions across a wider range of ages. Approval for the study was obtained from the Human Research Ethics Committee of the University of Sydney, New South Wales Department of Education, and Catholic Education Office. The study adhered to the tenets of the Declaration of Helsinki.

Details of survey methods are described elsewhere.[29] In brief, all primary and secondary schools across the Sydney metropolitan region were stratified into deciles, based on the socioeconomic status of the school location. A random sample, comprised of schools from each stratum (34 primary and 21 secondary), was used to provide a representative sample of Sydney children; there was a proportional mix of public and private/religious schools. All children in the year 1 and year 7 classes at the respective schools were invited to participate by school contact with parents. Informed consent from parents and verbal assent from each child were obtained.

Questionnaire Data

A detailed questionnaire for parents included questions about perinatal factors and birth parameters such as maternal smoking, breast-feeding, birth weight, and gestational age. In completing the questionnaire, parents were asked to use the child's hospital personal health record where possible. Other data, such as sociodemographic information (ethnicity, parental education, employment, and home ownership) and time in activities (near-work and outdoor) in the child were also obtained in parent questionnaires. The 12-year-old children completed a separate questionnaire, in which similar questions about time spent in near-work and outdoor activity were included.[30] Near-work activities in the 12-year-olds included outdoor leisure activities, watching television/videos/digital videos, doing homework, reading for pleasure, using a computer, and playing console games.

Examination

The eye examination included visual acuity (VA) assessment, cycloplegic autorefraction, subjective refraction, cover testing, ocular biometry, and dilated fundus examination. Distance VA was assessed for each eye separately using a logarithm of the minimum angle of resolution (logMAR) chart with and without any spectacle correction, if worn. The chart was retroilluminated with automatic calibration to 85 candelas/m^2 (CSV-1000, Vectorvision, Inc., Dayton, OH) and read at 8 feet (244 cm). Near VA testing was performed using the logMAR HOTV near vision chart at a distance of 33 cm. The card consists of 28 letters, ranging from 20/200 to 20/20 Snellen equivalent and is recorded using the logMAR scale. A matching HOTV card was available for children unable to read the letters. Cycloplegic autorefraction was performed using an RK-F1 autorefractor (Canon, Tokyo, Japan), because this method of examination has been shown to provide more reliable measurements in young children relative to other methods such as cycloplegic retinoscopy and noncycloplegic autorefraction.[31] Cycloplegia was induced using cyclopentolate 1% (1 drop), 2 minutes after corneal anesthesia with amethocaine 0.5%. Tropicamide 1% (1 drop) and phenylephrine 2.5% (1 drop) were also used in some children to obtain adequate mydriasis. Autorefraction was performed around 25 minutes after the cyclopentolate instillation. Ocular biometry was performed using the IOLMaster (Carl Zeiss-Meditec, Oberkochen, Germany). The accuracy and reproducibility of measurements using partial coherence interferometry has been reported.[32–34]

Anthropometric measures in the children included assessment of height and weight. The child's height was measured with shoes off, using a freestanding height rod. Body mass index (BMI) was calculated (weight [kilograms]/height [meters]^2).

Definitions

Hyperopia was defined as an SE refraction of +0.50 D or greater and was stratified as mild (+0.50 D or greater but <+2.00D) or moderate (+2.00 D or greater). Emmetropia included SE refraction from +0.49 to −0.49 D, and myopia was defined as an SE refraction of −0.50 D or less. "No significant ametropia" was assigned for the refractive limits, SE refraction –0.49 to +1.99 D. All of the refraction definitions refer to values obtained with cycloplegia. The refractive status was assigned based on the eye with the greatest ametropia. Astigmatism was defined as cylinder power ≥ 1.00 D, using negative power. With-the-rule astigmatism included cylinder axes between 1° and 15° or 165° and 180°, and against-the-rule astigmatism included cylinder axes between 75° and 105°. Oblique astigmatism was defined as cylinder axes between 16° and 74° or 106° and 164°.

Distance visual impairment was defined as VA<20/40. Amblyopia was defined as corrected VA < 20/40 that could not be attributed to any underlying structural abnormality of the eye or visual pathway, and in the presence of an amblyogenic risk factor. Strabismus included any heterotropia at near or distance vision; reduced convergence near point was defined as <6 cm when using the Royal Air Force rule. Abnormal stereoacuity was assigned for a partial or negative Lang II stereotest result in the younger sample[35] and for an abnormal result on TNO testing in the older sample (>120 seconds of arc).[36] Prematurity was defined as gestational age < 37 weeks and low birth weight as <2500 g.

Data Analysis

Data were analyzed using Statistical Analysis System software (SAS Institute, Cary, NC). Mixed models and logistic regression models were used to examine associations and subgroup differences. Multivariate analyses, performed separately for the children in years 1 and 7, were used to examine the impact of demographic factors (age, gender, ethnicity, parental education), perinatal factors (delivery type, birth weight, gestation age), and maternal factors (maternal age at birth of child, smoking during pregnancy, breast-feeding). All reported confidence intervals (CIs) are at the 95% level.

Results

Subjects

Of eligible children, 1765 year 1 (78.9%) and 2367 year 7 (75.3%) were given parental permission to participate. Of these, 38 were not examined as they were absent from school for the examination week in that school. Of the 473 nonparticipants in year 1, 53.7% were boys and 46.3% were girls. Nonparticipants in year 7 were predominantly European Caucasian (67.8%), and 51.6% were boys. Mean ages of participants were 6.7 years (range, 5.5–8.4) in year 1 and 12.7 (range, 11.1–14.4) in year 7. Basic demographic data for the 2 groups (referred to as 6-year-olds or 12-year-olds) are shown in Table 2 (available at http://aaojournal.org).

Table 3. Proportion (95% Confidence Intervals) of 6-Year-Olds and 12-Year-Olds with Hyperopia, Stratified by Gender and Ethnicity

	n (%)	Mild Hyperopia (+0.50 D ≤ SE Refraction < +2.00 D)	Moderate Hyperopia (SE Refraction ≥ +2.00 D)
6-year-olds			
Entire group	1724 (100.0)	80.5 (78.2–82.8)	13.2 (11.1–15.2)
Boys	875 (50.8)	82.2 (78.9–85.5)	10.9 (8.5–13.2)
Girls	849 (49.3)	78.8 (76.3–81.3)	15.5 (12.7–18.4)
European Caucasian	1096 (63.6)	81.2 (78.4–84.0)	15.7 (13.2–18.2)
East Asian	295 (17.1)	79.7 (74.8–84.6)	6.8 (4.0–9.5)
South Asian	40 (2.3)	75.0 (57.8–92.2)	2.5 (0.0–7.5)
Middle Eastern	83 (4.8)	78.3 (64.0–92.6)	8.4 (1.6–15.2)
12-year-olds			
Entire group	2340 (100.0)	65.1 (58.9–71.4)	5.0 (4.1–5.8)
Boys	1186 (50.7)	66.2 (59.9–72.5)	5.1 (3.8–6.5)
Girls	1154 (49.3)	64.0 (56.7–71.4)	4.7 (3.5–6.0)
European Caucasian	1401 (60.1)	75.3 (72.1–78.5)	6.4 (5.2–7.7)
East Asian	349 (15.0)	29.8 (22.0–37.6)	2.0 (1.0–3.0)
South Asian	127 (5.4)	44.1 (34.5–53.7)	0
Middle Eastern	163 (7.0)	68.7 (64.9–72.6)	7.4 (2.7–12.0)

D = diopters; SE = spherical equivalent.
Data not shown for mixed ethnicity or other ethnic groups with smaller samples, including Oceanian, indigenous Australian, African, and South American.

Prevalence of Hyperopia

Any hyperopia was the norm and was present in most children, including 93.7% (CI, 91.7%–95.6%) of the 6-year-olds and 70.1% (CI, 63.5%–76.7%) of the 12-year-olds (Table 3). Prevalences of moderate hyperopia were 13.2% and 5.0%, respectively. Moderate hyperopia was significantly higher among girls for the 6-year-olds only (15.5% vs. 10.9%, $P = 0.005$). Children of European Caucasian ethnicity had the highest prevalence of moderate hyperopia (Table 3).

Ocular Biometric Parameters and Anthropometry in Hyperopia

Comparisons of mean axial length, corneal curvature radius, and anterior chamber (AC) depth among children with emmetropia, mild hyperopia, and moderate hyperopia are shown in Figure 1A–C. As ocular biometric data for the right and left eyes were highly correlated (Pearson coefficient > 0.85, all parameters, among children in both age groups), only data for the right eye are presented. On average, eyes in children with moderate hyperopia were shorter in axial length and had shallower ACs and flatter corneas than those of similarly aged emmetropic children (all Ps < 0.05). The mean calculated lens power did not significantly differ between the eyes of children with moderate hyperopia or emmetropia (all Ps > 0.05; Fig 1D).

Anthropometry measures (height, weight, and BMI) were not significantly associated with refractive error in the 6-year-old sample (all Ps > 0.3) after adjusting for perinatal factors (low birth weight, breast-feeding, and prematurity). In the 12-year-old sample, mean height of children with moderate hyperopia was significantly lower than that of children with emmetropia (154.7 vs. 157.0 cm, $P = 0.03$); however, no differences in weight or BMI were evident ($P>0.1$).

Visual Acuity

Overall, in the 6-year-olds unilateral uncorrected visual impairment was present in 71 (4.1%), and bilateral impairment in 23 (1.3%). Using a definition of best available VA (based on the best acuity selected from uncorrected, presenting, or pinhole measures), the proportion with unilateral visual impairment was reduced to 1.8%, and that with bilateral impairment to 0.4%. Among the 227 6-year-olds with moderate hyperopia, unilateral presenting visual impairment was found in 21 (9.3%) and bilateral presenting visual impairment in 4 (1.8%).

Overall, 268 (11.4%) 12-year-olds had unilateral uncorrected visual impairment; of these, 249 (92.9%) could be improved with subjective refraction. In addition, bilateral visual impairment was improved in 173 of 175 children (98.9%). Of the 116 12-year-olds with moderate hyperopia, 18 (15.5%) had unilateral presenting visual impairment and 3 (2.6%) had bilateral presenting visual impairment. Presenting VA is shown in Table 4.

Childhood Activities and Socioeconomic Factors

Outdoor activity (>20 hours per week) was much more frequently undertaken by children with moderate hyperopia than by children with myopia, a finding confirmed in the 6-year-olds (38.8% vs. 8.2%, $P = 0.001$) and 12-year-olds (45.3% vs. 19.9%, $P<0.0001$). At age 6, however, there were no significant differences in the number of hours spent on near-work activity ($P>0.99$), which was defined to include drawing, painting, and/or writing; doing homework; reading; and playing handheld computer games. At age 12, more hours were spent on near work by children with myopia ($P<0.0001$), but hours spent were similar in the moderate hyperopia and "no significant ametropia" groups (odds ratio [OR], 1.2; CI, 0.7–1.9).

Moderate hyperopia at age 6 was more common in those with working mothers ($P = 0.02$) but was not associated with home ownership, parental education, or father's employment ($P>0.1$). At age 12, less maternal education was a borderline significant factor associated with moderate hyperopia ($P = 0.055$).

Ocular Conditions

Common eye conditions including amblyopia, strabismus, abnormal convergence, and reduced stereoacuity were all substantially more frequent in children with moderate hyperopia than in children without significant ametropia ($P<0.0001$; Table 5).

Both esotropia and exotropia were significantly associated with moderate hyperopia ($P<0.0001$), although among the children with strabismus and moderate hyperopia, the most common squint type was esotropia (70%). Among the children with strabismus in the absence of significant refractive error, however, proportions with esotropia were 42% and 48% at ages 6 and 12, respectively.

Astigmatism, when present in the hyperopic eye, was predominantly with-the-rule and oblique (both 48.4%) in 6-year-olds. In 12-year-olds, the axes were equally distributed (all 34.3%).

Birth Parameters and Perinatal Factors

Table 6 shows the univariate ORs for moderate hyperopia with selected perinatal and maternal factors. In multivariate analyses for the 6-year-olds that adjusted for demographic factors (gender, ethnicity, parental education, parental employment), there were significant associations of moderate hyperopia with younger maternal age at pregnancy (≤30 years, $P = 0.03$) and both parents employed ($P = 0.02$). A history of smoking during the pregnancy was not significant ($P = 0.07$). In 12-year-olds, multivariate analyses showed that the association of smoking during pregnancy with moderate hyperopia was borderline significant ($P = 0.055$), even after adjusting for maternal and perinatal factors (delivery type, low birth weight, early gestation age, admission to neonatal intensive care). When ethnicity was included as an explanatory variable, maternal smoking became nonsignificant ($P = 0.2$).

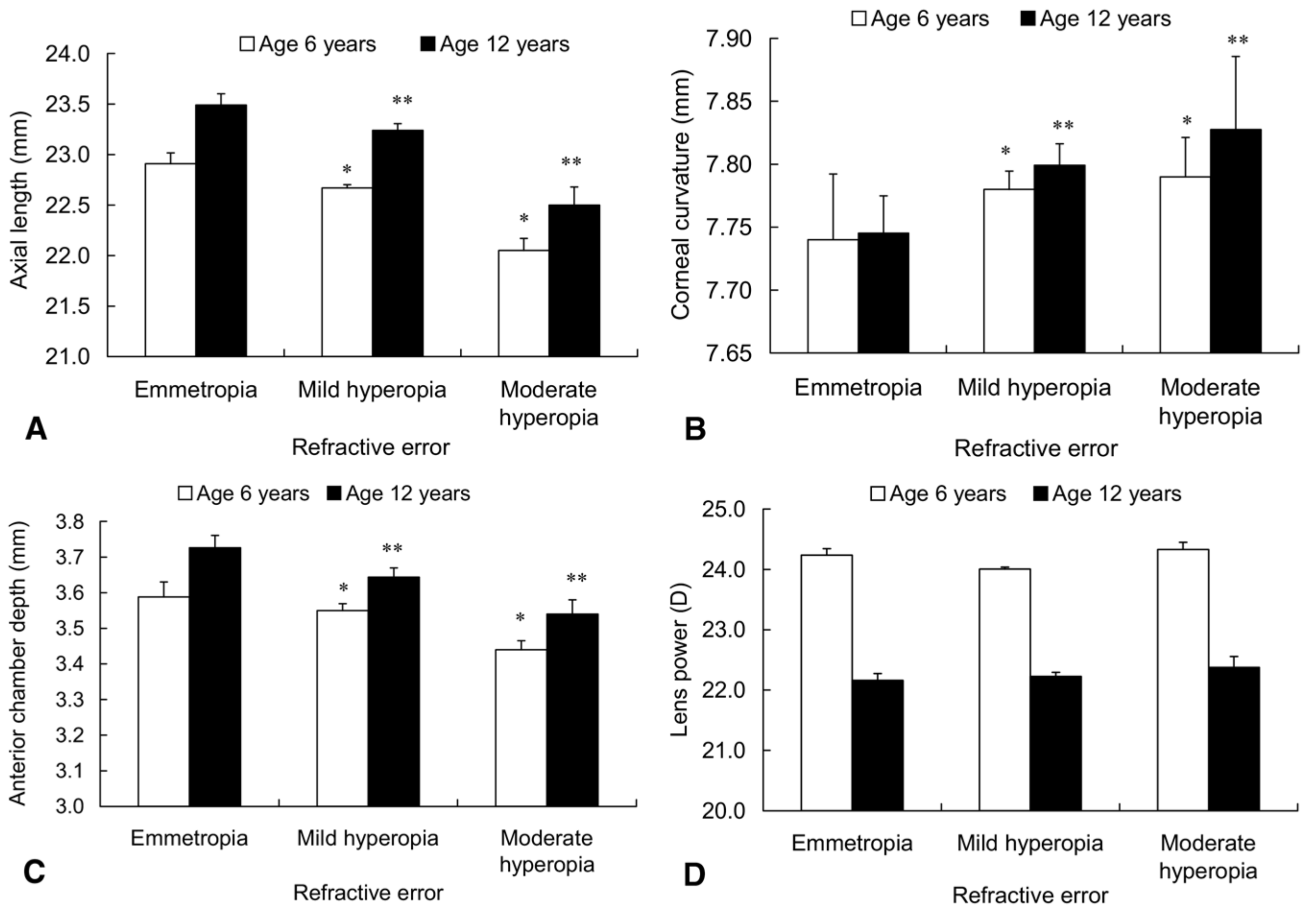

Figure 1. Ocular biometric parameters, including (**A**) axial length, (**B**) corneal radius of curvature, (**C**) anterior chamber depth, and (**D**) calculated lens power, among children with emmetropia, mild hyperopia, and moderate hyperopia, by age sample. D = diopters. Error bars, upper 95% confidence intervals. *$P<0.05$ compared with emmetropic children in year 1 (6 years old). **$P<0.05$ compared with emmetropic children in year 7 (12 years old).

A history of smoking during pregnancy was more frequent among women who were pregnant at or before age 30 (15.4%) than among older women (9.0%; χ^2, $P<0.0001$); exposure to passive smoking during pregnancy was also more prevalent among women who were pregnant at or before age 30, compared with older women (15.1% vs. 6.5%; χ^2, $P<0.0001$). After adjusting for markers of socioeconomic status (parental education, employment, and home ownership), the association between moderate hyperopia and maternal smoking was marginally significant in 6-year-olds ($P = 0.054$) but not in 12-year-olds ($P = 0.6$).

Table 4. Presenting Visual Acuity (Logarithm of the Minimum Angle of Resolution Letters) Tested with Spectacles, If Worn, of 6- and 12-Year-Olds

Refractive Status [Mean Distance Visual Acuity (SD)]	6-Year-Olds		12-Year-Olds	
	Worse Eye	*Better Eye*	*Worse Eye*	*Better Eye*
Moderate hyperopia	45.9 (7.5)*	49.2 (4.1)*	48.4 (12.4)*	55.9 (5.5)*
Mild hyperopia	49.4 (3.5)	51.1 (3.1)	56.6 (4.4)*	58.8 (3.2)*
Myopia	40.7 (10.5)*	45.3 (6.6)*	45.6 (11.9)*	51.7 (7.8)*
Emmetropia	48.5 (4.8)	50.7 (3.8)	55.2 (5.7)	58.1 (3.5)

SD = standard deviation.
*$P<0.05$ using emmetropia as referent, adjusting for age, gender, and ethnicity.

Discussion

In this population-based sample of predominantly European Caucasian schoolchildren, any hyperopia was by far the most common refractive state. Although moderate hyperopia was less prevalent in the 12-year-olds, it was strongly associated with other common eye conditions such as amblyopia and strabismus, as well as self-reported eyestrain symptoms and parent-reported learning difficulties.

Recent population-based studies of refractive error among children have reported prevalence of moderate hyperopia ranging from 1.4% among a sample of Nepalese children[8] to 14.5% of an urban sample of children from Chile.[9] Our overall prevalence of moderate hyperopia (8.4%) is comparatively higher than that reported in studies from China, India, Malaysia, Nepal, and South Africa[4–8,10,11] but lower than that from Chile.[9] Our findings are relatively similar to previous refraction studies of predominantly Caucasian childhood populations,[37,38] despite the considerable

Table 5. Prevalence and Odds Ratios for Common Eye Conditions and Symptoms among Children with Moderate Hyperopia (Spherical Equivalent Refraction ≥ +2.00 Diopters), Compared with Children without Significant Ametropia (−0.50 < Spherical Equivalent Refraction < +2.00 Diopters)

	6-Year-Olds			12-Year-Olds		
Associated Factor	*Moderate Hyperopia [% (n)]*	*No Significant Ametropia [% (n)]*	*Univariate Odds Ratio (Confidence Interval)*	*Moderate Hyperopia [% (n)]*	*No Significant Ametropia [% (n)]*	*Univariate Odds Ratio (Confidence Interval)*
Ocular associations						
Amblyopia	9.7 (22)	0.4 (6)	26.2 (10.5–65.3)	19.1 (22)	0.5 (9)	50.4 (22.5–113)
Strabismus	10.6 (24)	1.4 (20)	8.6 (4.6–15.8)	15.5 (18)	1.3 (25)	14.0 (7.4–26.4)
Abnormal convergence	15.8 (35)	9.0 (132)	1.9 (1.3–2.8)	23.9 (26)	13.0 (249)	2.1 (1.3–3.3)
Normal stereoacuity*	84.0 (189)	93.6 (1364)	0.4 (0.2–0.5)	79.0 (90)	98.4 (1887)	0.06 (0.04–0.1)
Astigmatism	13.7 (31)	6.1 (90)	2.4 (1.6–3.7)	30.2 (35)	5.7 (110)	7.1 (4.6–11.1)
Anisometropia†	9.7 (22)	0.1 (2)	78.8 (18.4–337)	36.2 (42)	0.26 (5)	217.8 (83.7–566)
Other associations (parent reported)						
Delay in milestones	8.6 (18)	9.3 (124)	0.9 (0.5–1.5)	11.5 (12)	7.5 (136)	1.6 (0.9–3.0)
Learning difficulties	14.2 (29)	12.1 (156)	1.2 (0.8–1.9)	29.0 (29)	14.2 (240)	2.5 (1.6–3.9)
Eyestrain symptoms‡	19.5 (40)	11.7 (154)	1.8 (1.2–2.7)	57.1 (64)	44.7 (833)	1.7 (1.1–2.4)

*Measured by Lang II stereotest in the 6-year-old sample and by TNO in the 12-year-old sample.
†Defined as >1.00 diopter.
‡Includes symptoms of blurred vision, sore eyes, double vision, or near-work–associated headache.

variation in definition for hyperopia, particularly for higher levels.

Gender differences in the prevalence of moderate hyperopia were statistically significant only for the younger sample of children (6 years). A higher prevalence of moderate hyperopia among girls has been documented in some other studies,[5,8–10] whereas findings for rural India,[11] Malaysia,[4] south China,[6] and South Africa[7] did not show any significant gender difference in prevalence. An age-related decrease in the prevalence of moderate hyperopia has also been reported,[4–6,9,10] though in areas where the estimated hyperopia prevalence is extremely low (<3%)[7,8,11] changes with age are usually not evident.

Association of Hyperopia with Other Eye Conditions

In addition to the high prevalence of strabismus and amblyopia in moderate hyperopia, anisometropia and astigmatism were also common. Anisometropia was present in 9.7% of the 6-year-olds and 36.2% of the 12-year-olds. Clinic-based studies of younger children have found that 28% with hyperopia of +2.0 D or greater had anisometropia,[39] whereas school-based studies have reported anisometropia in 2.8% of children with unilateral hyperopia (+0.50 D or greater) and 8.4% of children with bilateral hyperopia.[40] Longitudinal studies of Singaporean children have shown

Table 6. Exposure to Selected Perinatal and Maternal Factors in Children with Moderate Hyperopia (Spherical Equivalent Refraction ≥ +2.0 Diopters), Compared with Children without Significant Ametropia (−0.50 Diopters < Spherical Equivalent Refraction < +2.00 Diopters)

	6-Year-Olds			12-Year-Olds		
Risk Factor	*Moderate Hyperopia [% (n)]*	*No Significant Ametropia [% (n)]*	*Univariate Odds Ratio (Confidence Interval)*	*Moderate Hyperopia [% (n)]*	*No Significant Ametropia [% (n)]*	*Univariate Odds Ratio (Confidence Interval)*
Delivery type						
Normal	66.3 (132)	67.2 (878)	0.96 (0.7–1.3)	65.0 (65)	68.7 (1152)	0.8 (0.6–1.3)
Cesarean	23.6 (47)	18.9 (247)	1.3 (0.9–1.9)	19.0 (19)	17.1 (287)	1.1 (0.7–1.9)
Low birth weight						
<2500 g	7.1 (14)	6.1 (76)	1.2 (0.6–2.1)	6.9 (6)	5.9 (88)	1.2 (0.5–2.8)
<1500 g	0 (0)	0.5 (6)	-	0.0 (0)	0.4 (6)	-
Gestation						
<37 wks	9.5 (20)	7.6 (101)	1.3 (0.8–2.1)	7.2 (7)	8.6 (143)	0.8 (0.4–1.8)
≥42 wks	8.5 (18)	8.6 (114)	1.01 (0.6–1.7)	15.5 (15)	11.4 (189)	1.4 (0.8–2.5)
Breast-feeding						
Any	88.7 (188)	79.7 (55)	1.2 (0.8–1.9)	79.2 (80)	84.0 (1440)	0.7 (0.4–1.2)
>3 mos	88.7 (188)	86.4 (1169)	0.9 (0.7–1.3)	54.0 (54)	59.7 (1004)	0.7 (0.4–1.2)
Maternal smoking	16.4 (35)	11.3 (153)	1.5 (1.04–2.3)	21.6 (22)	16.3 (282)	1.4 (0.9–2.3)
Passive smoking during pregnancy	7.9 (17)	10.9 (146)	0.7 (0.4–1.2)	17.8 (18)	17.1 (293)	1.05 (0.6–1.8)
Maternal illness during pregnancy	10.6 (24)	13.5 (198)	0.8 (0.5–1.2)	34.0 (33)	38.5 (650)	0.8 (0.5–1.3)

that in those with unilateral or bilateral hyperopia the proportion with anisometropia decreased with older age (1.7% and 6.7%, respectively),[40] despite age-related increases in the prevalence of anisometropia overall, and a 7.6% cumulative incidence of anisometropia over 3 years. Our cross-sectional study of 2 samples of predominantly Caucasian schoolchildren with a higher cutoff for hyperopia is not directly comparable to the Singaporean study, and future longitudinal studies may be useful for examining the incidence and progression of anisometropia with higher levels of hyperopia.

Anisometropia is a well-known risk factor for amblyopia.[41] The tendency for the development of amblyopia is greater at lower levels of hyperopic anisometropia than with myopic anisometropia.[41] Recent studies have reported the impact of increasing age, showing that the prevalence and severity of amblyopia are greater in older children with anisometropia than in younger children.[42] This age-related association is one possible explanation for our finding that amblyopia was prevalent among the older children with moderate hyperopia. A less likely explanation would be improvements in screening methods, because vision screening services have remained virtually unchanged in Sydney. Vision screening in the neonatal setting and self-referral appear to be the most common methods for detecting eye problems.

Astigmatism was common among the children with moderate hyperopia, being more prevalent in 12-year-olds than 6-year-olds. Our previously reported findings for astigmatism in moderate hyperopia showed that the prevalence of all components of astigmatism (refractive, corneal, and internal astigmatism) was higher in 12-year-olds than in 6-year-olds[43] and that astigmatism in these older children is likely to be driven largely by corneal and lenticular changes.

Moderate hyperopia with or without other common eye conditions was associated with a higher prevalence of visual impairment in this study (11%–18%). Eyestrain symptoms and learning difficulties were also more common. Although evidence from the current literature suggests that hyperopia may be associated with poor reading performance,[20,21,44] whether adequate correction of hyperopia is likely to improve reading skills is not known.[21] The cluster of visually disabling conditions such as amblyopia is likely to be an important confounder.

Ocular Biometry

Findings in the current study highlight the significant differences in ocular biometry between children with hyperopia and those with emmetropia, as well as the differences between 6-year-olds and 12-year-olds. Our findings show that, in children with moderate hyperopia, mean axial length is significantly shorter and the mean corneal radius of curvature is significantly larger (flatter cornea) than in emmetropia. Age-associated differences in moderate hyperopia included longer axial length, flatter corneas, and weaker lens power.

Other oculometric studies of children with hyperopia have shown that axial length was highly correlated with SE refraction and that, in logistic regression analysis, axial length accounted for 47% of the variation in SE.[45] The correlation between corneal radius or lens radius and SE refraction, however, was not significant and suggests that axial length is the predominant oculometric correlate of hyperopia.

Smoking and Hyperopia

Factors associated with the persistence of moderate hyperopia and the underlying mechanisms that may be responsible for a failure of emmetropization are not well understood.[46] Recent studies have suggested that nicotinic acetylcholine receptors may be important in eye growth, and in animal studies, non–subtype-specific channel-blocking nicotinic antagonists were reported to inhibit the development of form-deprivation myopia.[47] In children, an association between passive exposure to parental smoking and hyperopic refraction has been reported in clinic-based samples,[48] but not confirmed in other studies.[49] We found that maternal smoking during pregnancy was more frequent among children with moderate hyperopia. However, this association was only borderline significant for children in both the 6- and 12-year age groups in multivariate analyses, and there was no significant association with passive smoking in pregnancy. Our data, therefore, only provide weak evidence to support a link between moderate hyperopia and smoking in pregnancy.

Strengths and Limitations

Some limitations of this study include the lack of refraction data for nonparticipants in the study and the use of self-reported time-based measures of near-work and physical activity. Because children with existing eye conditions may have been more likely to participate, it could be expected that the prevalence of hyperopia may have been slightly overestimated. However, a high participation rate and similar demographics in participants and nonparticipants suggest that our study sample was actually fairly representative, and selection bias, if present, would be only minimal. Measurement errors would be expected to dilute the reported associations. We have used standardized examination techniques and instruments with high reproducibility (autorefraction, IOLMaster) to minimize such errors.

In summary, although trends for increasing myopia prevalence have attracted much research and media attention, moderate hyperopia is relatively underresearched. This study reports the prevalence of moderate hyperopia in a population-based sample of Australian schoolchildren and the magnitude of the significant associations of this refractive error with amblyopia and strabismus. It also explores possible associations with perinatal and maternal risk factors. Maternal smoking may be a potentially modifiable risk factor, but this will need to be confirmed in other studies. Future studies that examine familial associations and the impact of moderate hyperopia on learning and development could provide useful further contributions.

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Table 1. Selected Studies of Hyperopia Prevalence

Author	Country	Definition of Hyperopia	N	Age (yrs)	Prevalence (%)
Kleinstein[37]	U.S.	SE ≥ 1.25 D in each meridian	2523	5–17	12.8
Zadnik[38]	U.S.	SE ≥ +1.25 D	2583	6–14	8.6
He[6]	Urban China	SE ≥ +2.0 D	454	12	2.0
			295	6	10.7
Zhao[5]	Rural China	SE ≥ +2.0 D	704	12	1.0–2.0
			199	6	7.0–16.0
Fan*	China (Hong Kong)	SE ≥ +2.0 D	7560	5–16	4.0
Maul[9]	Chile	SE ≥ +2.0 D	435	12	11.0–13.0
			588	6	20.0–26.0
Goh[4]	Malaysia	SE ≥ +2.0 D	534	12	0.6
			590	7	5.0
Murthy[10]	Urban India	SE ≥ +2.0 D	560	12	5.0
			494	6	13.0
Dandona[11]	Rural India	SE ≥ +2.0 D	534	12	0.8
			588	7	0.7
Pokharel[8]	Nepal	SE ≥ +2.0 D	481	12	<1.0
			444	6	2.0–3.0
Naidoo[7]	South Africa	SE ≥ +2.0 D	476	12	3.2
			458	6	2.8
Current study	Australia	SE ≥ +2.0 D	2353	12	5.0
			1741	6	13.2

D = diopters; SE = spherical equivalent.
Only studies using cycloplegic autorefraction are included.
*Fan DS, Lam DS, Lam RF, et al. Prevalence, incidence, and progression of myopia of school children in Hong Kong. Invest Ophthalmol Vis Sci 2004;45:1071–5.

Table 2. Comparison of Demographic Characteristics of 6-Year-Old Participants (n = 1740) and 12-Year-Old Participants (n = 2353)

	6-Year-Olds	12-Year-Olds
Mean age (range)	6.7 (5.5–8.4)	12.7 (11.1–14.4)
Gender [n (%)]		
Female	859 (49.4)	1163 (49.4)
Male	882 (50.7)	1190 (50.6)
Ethnicity [n (%)]		
European Caucasian	1122 (64.5)	1411 (60.0)
East Asian	299 (17.2)	352 (15.0)
Middle Eastern	85 (4.9)	129 (5.5)
South Asian	40 (2.3)	167 (7.1)
Mixed	137 (7.9)	178 (7.6)
Other*	55 (3.2)	112 (4.8)

*Indigenous Australian, Oceanian, African, and South American.