Comparison of Refraction and Ocular Biometry in European Caucasian Children Living in Northern Ireland and Sydney, Australia

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Purpose. To compare refraction and ocular biometry in European Caucasian children aged 6 to 7 years and 12 to 13 years, living in Sydney, Australia, and Northern Ireland.

Methods. All children had a comprehensive eye examination, including cycloplegic (cyclopentolate 1%) autorefraction and ocular biometry. Hyperopia was defined as a right spherical equivalent refraction (SER) of $\geq+2.00$ diopters (D), myopia as ≤-0.50 D, and astigmatism as a cylindrical error of ≥1.00 D.

Results. The mean SER was similar at age 6 to 7 years ($P = 0.9$); however, at 12 to 13 years, children in Northern Ireland had a significantly less hyperopic mean SER ($+0.66$ D) than children in Sydney ($+0.83$ D, $P = 0.008$). The prevalence of myopia, hyperopia, and astigmatism was significantly greater in Northern Ireland than Sydney at both ages (all $P < 0.03$). The distribution of refraction was highly leptokurtic in both samples, but less so in Northern Ireland (kurtosis: 6–7 years of age, 7.2; 12–13 years of age, 5.9) than Sydney (kurtosis: 6–7 years of age, 15.0; 12–13 years of age, 19.5).

Conclusions. European Caucasian children in Northern Ireland have a greater prevalence of myopia, hyperopia, and astigmatism when compared to children living in Sydney. Risk factors for myopia such as parental myopia, parental education, and educational standards do not appear to explain the differences. Further work on levels of near work and time spent outdoors is required. (*Invest Ophthalmol Vis Sci.* 2012;53:4021–4031) DOI:10.1167/iovs.12-9556

The prevalence of myopia varies significantly according to location and ethnicity.[1-6] School children from areas of East Asia have a particularly high prevalence of myopia[1,7-13] as compared to other ethnic groups.[4,14-27] There is debate about whether such variation results from genetic or environmental factors,[28-32] but, while a family history of myopia adds an additional risk of developing myopia,[33-36] ethnic differences may be attributed to cultural and behavioral differences, including attitudes to education.[28,31]

Comparison between age-matched children of Chinese ethnicity highlights the extent of variation with location. The Singapore Cohort Study of Risk Factors for Myopia (SCORM) sample of children (mean age, 13.7 years), has reported a prevalence of almost 70% in Singapore,[37] while, in a similar age group from rural Chongqing, China, the prevalence is significantly lower at 21.1%.[38] Rates as low as 0.7% have been reported in 12- to 13-year-old children from Laos (Casson R, oral communication, September 2011), who are also part of the East Asian population genetic cluster. Comparison of refractive error in children of Chinese ancestry living in Sydney and Singapore has found that time spent outdoors is the dominant contributing factor to the almost 10-fold difference in prevalence of myopia between the two samples.[2]

Less is known about the variation in European Caucasian populations living in different geographic locations.[18-27] The prevalence of myopia in Australian children appears to be particularly low.[25,26] In comparison to the prevalence of myopia (11.9%) in 12-year-old children from the Sydney Myopia Study (SMS),[25] data from other sites have reported higher levels of myopia, ranging from 12.8% in Poland,[24] through 18.3% in the United States,[35] 29.4% in the United Kingdom,[21] and 49.7% in Sweden.[23] Such comparisons are difficult because of methodologic differences between studies, and to date no study, using similar methods, has directly compared the distribution of refractive error in populations of European Caucasian ethnicity living in different geographic locations.

The Northern Ireland Childhood Errors of Refraction (NICER) study has investigated a predominantly Caucasian sample of 6- to 7-year-old and 12- to 13-year-old children living in Northern Ireland, which is well matched in age and ethnicity to the European Caucasian children from the SMS study. The present study therefore compared refractive errors and ocular biometric parameters in these two population samples.

METHODS

Population

Two population-based samples of 6- to 7-year-old and 12- to 13-year-old children were used from the SMS (2003–2005) and the NICER (2006–

2008) studies. Both studies were school based and used a stratified random cluster design. The study area was organized into socioeconomic strata from government supplied data: quartiles in NICER (provided in the public domain by Northern Ireland Statistics and Research Agency: http://www.nisra.gov.uk/) and deciles in SMS (provided in the public domain by the Australian Bureau of Statistics: http://www.abs.gov.au/census). From each stratum, schools were randomly selected to ensure a representative sample was obtained. The participation rate was 79% and 75% in the SMS study and 57% and 60% in the NICER study for the 6- to 7-year-old and 12- to 13-year-old age groups, respectively. These methodologies have been reported previously.[39,40]

In the SMS study, children's ethnicity was determined by the self-identified ethnic origin of both parents, using ethnic categories consistent with the Australian Standard Classification of Cultural and Ethnic Groups.[41] These categories align with modern knowledge of human population genetic clusters.[42] In the NICER study, ethnicity was assessed by the study coordinator and confirmed by parental questionnaire. Both study populations were predominantly European Caucasian at both ages 6 to 7 and 12 to 13 years (SMS, 63.7% and 59.7%, respectively; NICER, 98.2% and 98.8%, respectively). For this analysis, only children who were of European Caucasian ethnicity were included.

Procedures

Written informed consent was obtained from parents or guardians of all children before examination. Ethical approval for SMS was obtained from the Human Research Ethics Committee, University of Sydney, the New South Wales Department of Education and Training, and the Catholic Education Office of the Archdiocese of Sydney. For the NICER study, approval was obtained from the University of Ulster's Research Ethics Committee. Both studies adhered to the tenets of the Declaration of Helsinki.

All children had a comprehensive eye examination including cycloplegic autorefraction. Cycloplegia was induced by cyclopentolate 1% following the instillation of a local anesthetic. In NICER, one drop of cyclopentolate was administered. In SMS, two drops were instilled in two cycles, 5 minutes apart, with the addition of tropicamide 1%. Autorefraction was measured at least 20 minutes after the instillation of cycloplegic drops, by using a table-mounted autorefractor (model RK-F1; Canon, Tokyo, Japan) in Sydney and a binocular open-field autorefractor (model SRW-5000; Shin-Nippon, Tokyo, Japan) in Northern Ireland. A comparison of results obtained from similar model autorefractors from these manufacturers using cycloplegia has shown that they are comparable for both spherical and cylindrical measures.[43] Adequacy of cycloplegia was assessed before autorefraction, by pupil dilation >6 mm, and absence of pupil reaction to light and accommodative stimulus, in Sydney. In Northern Ireland, cycloplegia was assessed by absence of the pupillary light reflex and accommodative amplitude <2 D.

Ocular biometry, including corneal radius of curvature (CR) and axial length (AL), was measured with a noncontact optical biometer (IOLMaster; Carl Zeiss Meditec Inc., Jena, Germany). The validity of AL measurements was assessed by a signal-to-noise ratio ≥2.0, with a minimum of 3 (NICER) or 5 (SMS) measures taken. In both studies, three valid measurements of CR were obtained along the steepest (CR1) and flattest (CR2) meridians.

Height was measured with a free-standing height rod and weight was measured with Tanita digital scales (Tanita, Middlesex, United Kingdom). Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared.

A questionnaire was also administered at both sites, which provided information on parental factors including education level and parental myopia. In the SMS study, parental myopia was determined either by spectacle prescription or analysis of spectacle-use questions, as previously described and validated.[44] In the NICER study, parents were asked whether they "wear spectacles" and if they are "short-sighted (needs spectacles to see far away)," with an affirmative response being used to classify them as myopic. Parental education was dichotomized into either tertiary or higher or lower education level for both studies.

Definitions

In both studies, refractive status was determined by the spherical equivalent refraction (SER), calculated as sphere + ½ cylinder. Myopia was defined as a SER ≤−0.50 D, hyperopia as ≥+2.00 D, and refractive astigmatism as ≥1.00 D. Corneal radius of curvature is defined as the mean of the flattest and steepest corneal measures. The axial length–corneal radius ratio (AL/CR) was calculated as axial length, divided by the mean radius of curvature. There was a significant correlation between right and left eyes for SER, CR, and AL for both the 6- to 7-year-old age group (SMS: $r = 0.91, 0.98,$ and 0.47, respectively; NICER: $r = 0.90, 0.97,$ and 0.97, respectively; all $P < 0.0001$) and the 12- to 13-year-old age group (SMS: $r = 0.87, 0.37,$ and 0.29, respectively; NICER: $r = 0.89, 0.98,$ and 0.96, respectively; all $P < 0.0001$). As such, data were presented for the right eye only, with the exception of Figure 3, in which data from both eyes were pooled to examine the relationship between spherical refraction and astigmatism for individual eyes.

Statistical Analyses

Statistical analysis was performed with IBM SPSS Predictive Analytics Software (v. 19; IBM, New York City, NY). Analysis of variance (ANOVA) and χ^2 analyses were used to determine differences in mean and prevalence values between the Sydney and Northern Ireland samples. Analysis of covariance (ANCOVA) was performed to account for the impact of anthropometry on ocular biometry. Measures of kurtosis and skewness were calculated for distributions. The Kolomogrov-Smirnov test was used to assess normality of distributions. To determine the impact of ocular biometric and anthropometric parameters on refraction, Pearson correlation coefficients were calculated and age-adjusted linear regression analysis was performed.

Results

Distribution of Refractive Errors

A total of 1497 children of European Caucasian ethnicity, aged 6 to 7 years, were included in the analysis: 1105 from Sydney and 392 from Northern Ireland. The 12- to 13-year-old age group sample included 2067 children in total, with 1406 from Sydney and 661 from Northern Ireland. Population characteristics for both samples are included in Table 1. Children living in Northern Ireland had a significantly higher prevalence of myopic, hyperopic, and astigmatic refractive errors in both the 6- to 7-year-old and the 12- to 13-year-old age groups than children living in Sydney. In addition, the children from Northern Ireland were significantly taller, heavier, and had a higher mean BMI than children in Sydney in both age samples (all $P < 0.0001$).

The mean SER of 6- to 7-year-old children from Sydney and Northern Ireland was +1.40 and +1.41 D, respectively ($P = 0.9$). In contrast, 12- to 13-year-old children from Sydney had a significantly more hyperopic SER (+0.83 D) than children from Northern Ireland (+0.66 D, $P = 0.008$). The distributions of SER for 6- to 7-year-old and 12- to 13-year-old children from Northern Ireland and Sydney were leptokurtic (Fig. 1). Kurtosis was significantly greater in Sydney (15.0) than Northern Ireland (7.2) in the younger group, while in the older group kurtosis was higher again in Sydney (19.54) than in Northern Ireland (5.86), where kurtosis appeared to have declined.

The distributions of cylinder power in the two locations were quite different (Fig. 2), with a much higher percentage of
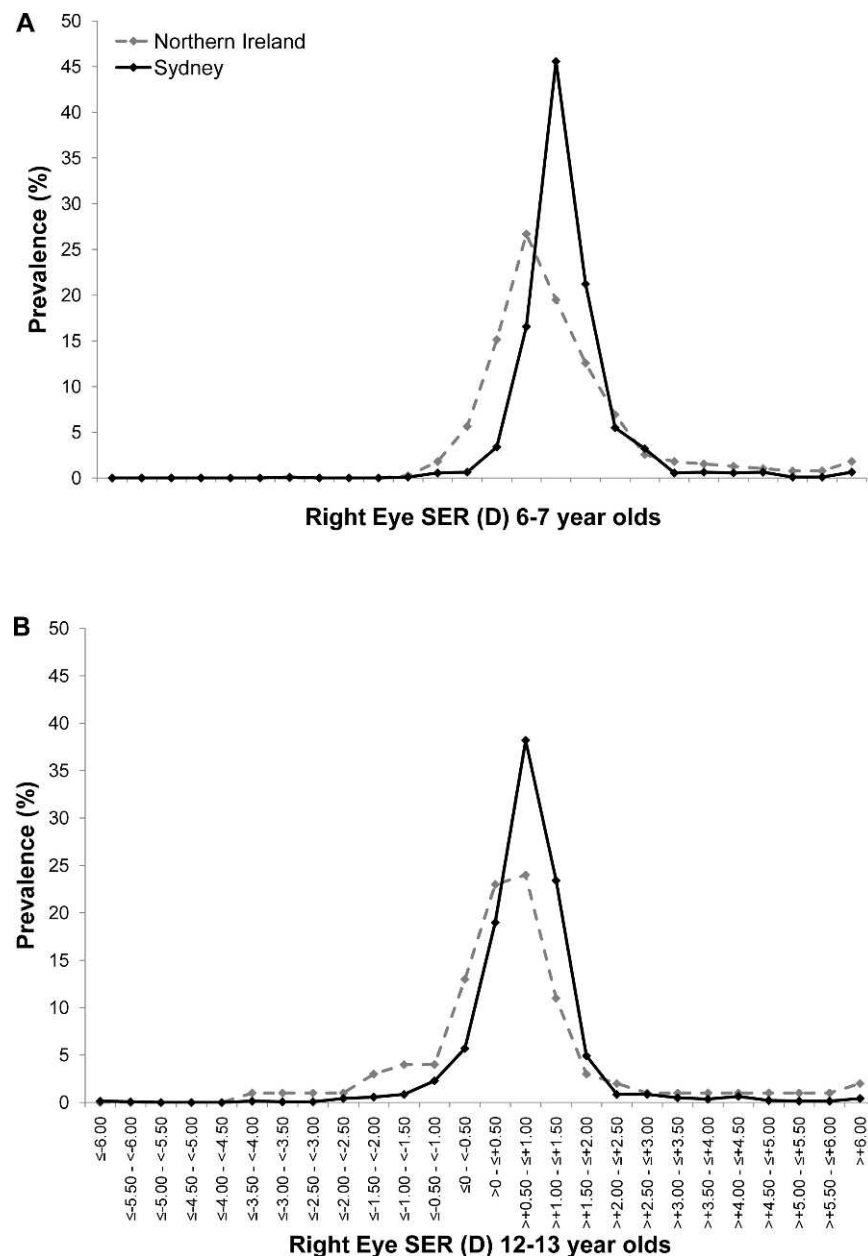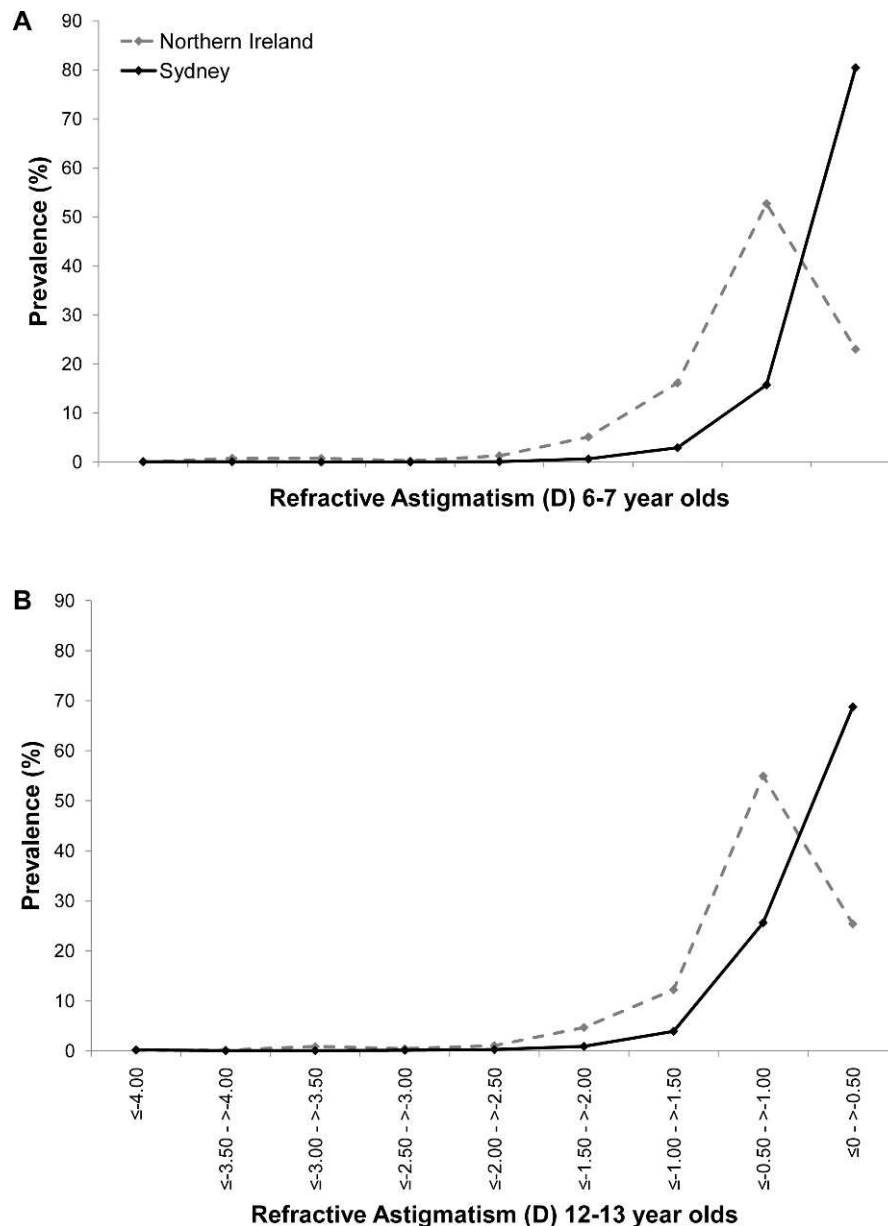
FIGURE 1. The distribution of refractive errors in European Caucasian children in Sydney and Northern Ireland. (A) Six- to 7-year-old age group. (B) Twelve- to 13-year-old age group.

children in Sydney having minimal levels of astigmatism than in Northern Ireland. Mean cylindrical refractive error was higher in Northern Ireland in the younger group (−0.69 D vs. −0.25 D, $P < 0.0001$). This was also seen in the 12- to 13-year-old age group (−0.64 D vs. −0.35 D, $P < 0.0001$). Figure 3 shows that for each level of refractive error, including emmetropia, there was markedly less astigmatism in children from Sydney than in those from Northern Ireland, for both age groups. This difference was statistically significant for children with emmetropic and hyperopic spherical refractions in both age groups (all $P < 0.0001$). However, the difference in astigmatism between children from Northern Ireland and Sydney with myopia was not statistically significant at either 6 to 7 years of age ($P = 0.1$) or 12 to 13 years of age ($P = 0.07$), but the groups were small.

Comparison of Parental Myopia and Education

In the 6- to 7-year-old age group, the proportion of children with one or both of their parents myopic in Northern Ireland (49.4%) was significantly greater than for Sydney children (38.6%, $P = 0.002$). However, there was no significant difference in the proportion of children with both parents myopic in Northern Ireland (7.6%) and Sydney (5.8%, $P = 0.3$). For the 12- to 13-year-old age group, there was no significant difference between children from Northern Ireland and Sydney in the proportion of children with either one or both parents with myopia (40.9% and 37.4%, respectively; $P = 0.2$) or both parents with myopia (6.8% and 4.7%, respectively; $P = 0.1$). The proportion of children whose parents (one or both) had completed some tertiary education was significantly lower in Northern Ireland than Sydney for both the 6- to 7-year-old

FIGURE 2. The distribution of refractive astigmatism in European Caucasian children in Sydney and Northern Ireland. (**A**) Six- to 7-year-old age group. (**B**) Twelve- to 13-year-old age group.

(52.1% and 79.9%, respectively; $P < 0.0001$) and the 12- to 13-year-old children (49.0% and 71.5%, respectively; $P < 0.0001$).

A stepwise linear regression model using SER as the dependent variable and location, and parental myopia and parental education as covariates, was constructed. For the 6- to 7-year-old age group, parental myopia was the strongest determinant of refraction and alone produced an r^2 of 0.018. Addition of location to the model significantly increased r^2 to 0.025 ($P = 0.005$), with both variables remaining significant. Parental education was not significant on univariate analysis ($P = 0.8$) and its addition to the model did not significantly change r^2 ($P = 0.7$). Similarly, in the 12- to 13-year-old age group, parental myopia alone produced an r^2 of 0.033; with addition of location, the r^2 value significantly increased to 0.042 ($P < 0.0001$) and both remained significant. Again, addition of parental education did not significantly increase the strength of the model ($P = 0.3$).

Comparison of Ocular Biometry

Following adjustment for the difference in height between sites, children in Northern Ireland had a shorter mean axial length at 6 to 7 years of age ($P < 0.0001$) and a longer axial length at 12 to 13 years of age ($P < 0.0001$) than did Sydney children (Table 2). The AL/CR ratio was not significantly different in 6- to 7-year-old children from Northern Ireland (2.9) and Sydney (2.9, $P = 0.08$); however, it was greater in children from Sydney (2.99) than in those from Northern Ireland (2.97, $P < 0.0001$) at age 12 to 13 years. Corneal radius was significantly larger in children from Northern Ireland both at ages 6 to 7 years ($P < 0.0001$) and 12 to 13 years ($P < 0.0001$).

The AL/CR ratio was leptokurtic in both Northern Ireland and Sydney in both age groups (Table 2). AL was normally distributed in the 6- to 7-year-olds from both Northern Ireland and Sydney and in 12- to 13-year-olds from Sydney. However,
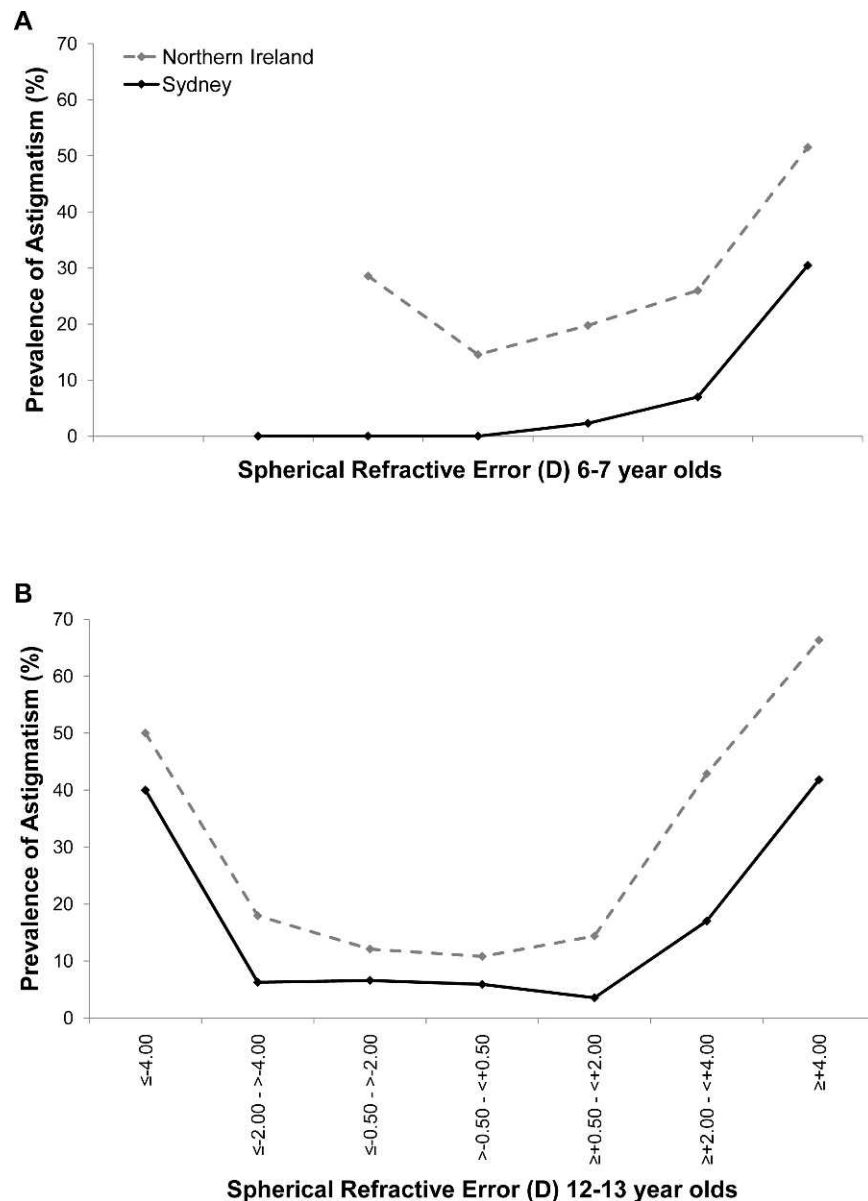
FIGURE 3.   The prevalence of significant refractive astigmatism, according to spherical refraction of European Caucasian children living in Northern Ireland and Sydney, pooled for both eyes. (**A**) Six- to 7-year-old age group. (**B**) Twelve- to 13-year-old age group.

the distribution of AL in 12- to 13-year-olds from Northern Ireland showed some kurtosis (kurtosis = 1.2).

There was a significant negative correlation between AL and SER in both Northern Ireland and Sydney at ages 6 to 7 years and 12 to 13 years (Tables 3 and 4, respectively). This relationship remained strong in age-adjusted regression analysis. There was an even stronger negative correlation between AL/CR and SER in Northern Ireland and Sydney at both ages, which also remained significant after adjustment for age. A small but significant positive relationship was present between CR and SER in Northern Ireland at ages 6 to 7 years and 12 to 13 years. This relationship was also evident in children from Sydney at age 12 to 13 years, but not at age 6 to 7 years.

Comparison of Anthropometry

At age 6 to 7 years there was no significant relationship between SER and anthropometric measures (Table 3). At age 12 to 13 years there was a small but significant inverse correlation between height and SER in both Northern Ireland and Sydney (Table 4). On regression analysis this relationship remained significant in Sydney ($r^2 = 0.02$, $P < 0.0001$), with each 1-cm increase in height associated with a decrease in refraction of -0.02 D. However, this relationship was no longer significant in Northern Ireland ($r^2 = 0.01$, $P = 0.09$). A similar small, but significant, association was present between weight and SER in Sydney and this remained significant after adjustment for age ($r^2 = 0.009$, $P = 0.004$). This relationship was not evident in the Northern Ireland sample. The small positive correlation between BMI and SER in children from Northern Ireland was not significant after adjustment for age.

Relationship between Anthropometry and Ocular Biometry

Height was significantly correlated with AL in both Northern Ireland and Sydney for both age samples (6–7 years of age: $r =$

TABLE 1. Characteristics of 6- to 7-Year-Old and 12- to 13-Year-Old European Caucasian Children Living in Northern Ireland and Sydney

	6- to 7-Year-Olds			12- to 13-Year-Olds		
	Northern Ireland ($n = 392$)	Sydney ($n = 1105$)	P Value	Northern Ireland ($n = 661$)	Sydney ($n = 1406$)	P Value
Mean age, y	7.1	6.7	<0.0001	13.1	12.7	<0.0001
Female, %	50.5	50.4	0.9	49.5	47.4	0.4
Myopia ≤ -0.50 D, %*	2.0	0.7	0.03	15.0	4.6	<0.0001
Hyperopia $\geq +2.00$ D, %*	22.3	12.0	<0.0001	11.8	4.4	<0.0001
Astigmatism ≥ 1.00 D, %†	24.3	3.8	<0.0001	19.7	5.6	<0.0001
Height, cm	125.5	121.2	<0.0001	160.6	156.6	<0.0001
Weight, kg	26.6	24.0	<0.0001	53.9	49.9	<0.0001
BMI, kg/m^2	16.8	16.2	<0.0001	20.8	20.2	0.001

* Based on SER of the right eye.
† Based on right eye prevalence.

0.2, $P < 0.0001$ and $r = 0.3$, $P < 0.0001$, respectively; 12–13 years of age: $r = 0.2$, $P < 0.0001$ and $r = 0.1$, $P < 0.0001$, respectively). There was also a small but significant correlation between height and CR in both Northern Ireland and Sydney (6–7 years of age: $r = 0.1$, $P = 0.01$ and $r = 0.2$, $P < 0.0001$, respectively; 12–13 years of age, $r = 0.1$, $P = 0.006$ and $r = 0.08$, $P = 0.004$, respectively). Height was also related to AL/CR ratio in 12- to 13-year-olds from Northern Ireland ($r = 0.08$, $P = 0.04$) and Sydney ($r = 0.1$, $P < 0.0001$) but not in 6- to 7-year-olds.

Greater weight was related to longer AL in Northern Ireland and Sydney at age 6 to 7 years ($r = 0.2$ and 0.2, respectively; $P < 0.0001$), but only in Sydney for the 12- to 13-year-old age group sample ($r = 0.1$, $P < 0.0001$). Similarly, weight was significantly related to CR in 6- to 7-year-olds in both Northern Ireland and Sydney ($r = 0.2$ and 0.1, respectively; $P < 0.0001$), but only in Sydney for 12- to 13-year-olds ($r = 0.1$, $P = 0.02$). AL/CR ratio was significantly correlated with weight in the Sydney samples (6–7 years of age: $r = 0.1$, $P = 0.03$; 12–13 years of age: $r = 0.1$, $P = 0.004$) but not in children from Northern Ireland.

In 6- to 7-year-olds from Northern Ireland, BMI was correlated with AL ($r = 0.1$, $P = 0.05$) and CR ($r = 0.1$, $P = 0.01$). In 6- to 7-year-olds from Sydney, BMI was not related to AL or CR. In 12- to 13-year-olds, BMI was significantly and positively correlated with AL in Sydney ($r = 0.1$, $P = 0.01$) and negatively correlated in Northern Ireland ($r = -0.1$, $P = 0.03$). BMI was also negatively correlated with AL/CR ratio in Northern Ireland for 12- to 13-year-olds ($r = -0.1$, $P = 0.01$), but not in Sydney.

DISCUSSION

This comparison of age- and ethnicity-matched children of European Caucasian origin from the SMS and NICER studies has shown that the prevalence of myopia, hyperopia, and astigmatism is significantly higher in Northern Ireland than in Sydney in both 6- to 7-year-olds and 12- to 13-year-olds. The mean SER was similar in the two locations in the younger age group, but was significantly lower in Northern Ireland than in Sydney at the age of 12 to13 years, probably owing to a greater shift towards myopia with increasing age in Northern Ireland.

There are few comparable population-based studies on children of European Caucasian origin from other sites. The Aston Eye Study[21] has reported a prevalence of myopia for 12- to 13-year-old European Caucasian children in the United Kingdom of 29.4%. The prevalence of myopia in Poland is 13.9% in urban children of this age, and 9.4% in children from rural areas.[24] In white children aged 12 to13 years in the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error study, the prevalence is 23.8% (Mutti D, oral communication, September 2011), and the highest value reported for children of European origin is 49.7% at the age of 12 years in a school-based sample in Sweden.[23] Thus, there is marked variation in the prevalence of refractive errors in European Caucasian children, just as there is in children of East Asian origin.

A major strength of this study is that the methods used in the two component studies were very similar, involving school-based recruitment, cycloplegic autorefraction, and IOLMaster measurements of biometry. As the protocol for cycloplegia was

TABLE 2. SER and Ocular Biometric Parameters in European Caucasian Children Living in Sydney and Northern Ireland

	Northern Ireland					Sydney					
	Mean	Range	Kurtosis	Skewness	K-S	Mean	Range	Kurtosis	Skewness	K-S	P*
6- to 7-year-olds											
SER, D	+1.41	−1.13 to 9.00	7.2	2.2	<0.0001	+1.40	−3.22 to 8.50	15.0	2.5	<0.0001	0.9
Axial length, mm	22.51	19.5 to 24.7	0.4	−0.3	0.2	22.58	19.6 to 24.6	0.38	−0.2	0.2	<0.0001
Corneal radius, mm	7.82	7.1 to 8.6	−0.2	0.1	0.1	7.77	7.0 to 8.7	−0.1	0.2	0.03	<0.0001
AL/CR ratio	2.88	2.5 to 3.1	1.4	−0.8	<0.0001	2.89	2.5 to 3.2	2.2	−0.6	<0.0001	0.08
12- to 13-year-olds											
SER, D	+0.66	−5.63 to 10.75	5.86	1.16	<0.0001	+0.83	−8.93 to 8.37	19.54	0.30	<0.0001	0.008
Axial length, mm	23.30	19.2 to 27.5	1.22	−0.09	0.04	23.24	19.8 to 26.3	0.72	0.01	0.2	<0.0001
Corneal radius, mm	7.84	7.1 to 8.8	0.08	0.12	0.2	7.77	6.8 to 9.0	0.43	0.15	0.2	<0.0001
AL/CR ratio	2.97	2.5 to 3.4	2.05	−0.40	<0.0001	2.99	2.7 to 3.4	2.82	0.08	<0.0001	<0.0001

K-S, Kolmogorov-Smirnov test for normality.
* P value refers to difference in mean between Northern Ireland and Sydney. When ocular biometry is compared, P values are adjusted for height.

TABLE 3. The Association of Ocular Biometric and Anthropometric Parameters and SER in 6- to 7-Year-Old European Caucasian Children Living in Northern Ireland and Sydney

	Northern Ireland			Sydney		
	Pearson Correlation	**β Coefficient (CI)***	**Model R^{2*}**	**Pearson Correlation**	**β Coefficient (CI)***	**Model R^{2*}**
Axial length, mm	−0.5†	−0.99 (−1.1 to −0.8)†	0.3	−0.4†	−0.51 (−0.6 to −0.4)†	0.2
Corneal radius, mm	0.2‡	0.87 (0.3 to 1.4)‡	0.03	0.04	0.14 (−0.05 to 0.3)	0.002
AL/CR ratio	−0.8†	−12.7 (−13.7 to −11.7)†	0.6	−0.7†	−9.9 (−9.2 to −8.0)†	0.4
Height, cm	0.06	0.02 (−0.007 to 0.05)	0.005	−0.01	−0.003 (−0.01 to 0.006)	0.001
Weight, kg	0.08	0.03 (−0.005 to 0.06)	0.007	−0.003	−0.002 (−0.01 to 0.01)	0
BMI, kg/m²	0.06	0.04 (−0.03 to 0.1)	0.004	0.005	0.002 (−0.02 to 0.03)	0

CI, 95% Confidence Intervals.

* In regression model, SER was the dependant variable, with each biometric or anthropometric variable as an explanatory variable; all analyses were adjusted for age.

† Significant to the level of $P \leq 0.001$.

‡ Significant to the level of $P \leq 0.05$.

slightly different between the two studies, with both using cyclopentolate 1% but with the addition of tropicamide 1% in Sydney, this could be a potential source of variation in refractive errors between Northern Ireland and Sydney. However, previous research has shown that there is no significant difference in the cycloplegic effect obtained from cyclopentolate alone versus a combination of cyclopentolate and tropicamide in children with light irises,[45] and adequacy of cycloplegia was rigorously assessed in both studies before refraction. Additionally, the differences in the prevalence of refractive errors noted between Sydney and Northern Ireland are not consistent with a difference in the adequacy of cycloplegia between sites, because there were more cases of myopia and hyperopia in Northern Ireland and fewer cases of myopia and hyperopia in Sydney, whereas inadequate cycloplegia causes overestimation of myopia and underestimation of hyperopia.

There was also an average 6-month age difference between the two locations. While this is statistically significant, it is of a magnitude that is unlikely to be responsible for the significant differences in refraction between sites. Another difference between the population samples is the fact that while both are of European Caucasian ethnicity, the population of Northern Ireland is overwhelmingly Anglo-Celtic in origin, whereas that of Sydney is more diverse, with a proportion having ancestry from Northern, Southern, and Eastern Europe. The European Caucasian population in Sydney is nevertheless predominantly Anglo-Celtic in origin.

As the differences in refractive errors between Northern Ireland and Sydney are so pronounced, a possible explanation is that the process of emmetropization is different in each location. To investigate this, observations need to be interpreted within the framework of current knowledge about refractive development in children. Briefly, children are predominantly hyperopic at birth, with a normal distribution of refractive errors.[46,47] In the first year or two after birth, the cornea stabilizes,[48] but the refractive distribution becomes tighter, with reductions in both myopia and hyperopia, leading to substantial leptokurtosis with a mean SER that is approximately between 1 and 2 D.[46,47] This appears to involve matching the axial length of the eye to the corneal radius, which produces a leptokurtic distribution of the AL/CR ratio by the age of 6 to 7 years.[26] After this time, axial length continues to increase, and hyperopic errors are further reduced, while myopic errors increase in prevalence.[48,49]

In both Northern Ireland and Sydney, the distributions of SER were leptokurtic, while AL and CR were both normally distributed. In addition, there were strong correlations of AL and AL/CR with SER in both locations, but the correlations of CR with SER were much lower, although statistically significant. These features are commonly seen during childhood, suggesting that the process of emmetropization is similar in Northern Ireland and Sydney and that the different refractive outcomes result from relatively subtle modulation of a common emmetropization process.

TABLE 4. The Association of Ocular Biometric and Anthropometric Parameters and SER in 12- to 13-Year-Old European Caucasian Children Living in Northern Ireland and Sydney

	Northern Ireland			Sydney		
	Pearson Correlation	**β Coefficient (CI)***	**Model R^{2*}**	**Pearson Correlation**	**β Coefficient (CI)***	**Model R^{2*}**
Axial length, mm	−0.68†	−1.3 (−1.35 to −1.15)†	0.47	−0.32†	−0.4 (−0.47 to −0.34)†	0.10
Corneal radius, mm	0.09‡	0.6 (0.11 to 1.11)‡	0.02	0.07‡	0.3 (0.07 to 0.49)‡	0.08
AL/CR ratio	−0.86†	−13.9 (−14.55 to −13.26)†	0.73	−0.70†	−8.9 (−9.39 to −8.43)†	0.49
Height, cm	−0.09‡	−0.02 (−0.03 to 0.003)	0.01	−0.13†	−0.02 (−0.02 to −0.009)†	0.02
Weight, kg	0.03	0.007 (−0.004 to 0.018)	0.008	−0.08†	−0.006 (−0.011 to −0.002)‡	0.009
BMI, kg/m²	0.08‡	0.04 (0.005 to 0.08)	0.013	−0.03	−0.009 (−0.02 to 0.005)	0.004

CI, 95% Confidence Intervals.

* In regression model, SER was the dependant variable, with each biometric or anthropometric variable as an explanatory variable; all analyses were adjusted for age.

† Significant to the level of $P \leq 0.001$.

‡ Significant to the level of $P \leq 0.05$.

The children from Northern Ireland were significantly taller, heavier, and had higher BMI than the children in Sydney at both ages. Given the difference in stature, the correlations between SER and anthropometric measures were investigated. While the literature is far from consistent,[50-53] some studies have shown that greater height is associated with a more myopic refraction.[54-57] Statistically significant associations of SER with height were detected in the 12- to 13-year-olds, but not in the younger group, at both sites, but regression analysis suggested that the effects were very small and could not account for the differences in refraction between Northern Ireland and Sydney. The relationship between axial length and height has been well documented,[50,54,58] but the correlations of SER with height were much lower than those of axial length with height, showing that emmetropization largely eliminated any relationship between height and refraction in both locations.

The major feature of these data is that at both the ages of 6 to 7 years and 12 to 13 years, there are fewer cases of myopia *and* fewer cases of hyperopia in Sydney than in Northern Ireland. Emergence of myopic refractive errors with growth and associated axial elongation throughout childhood often coincides with a parallel decrease in hyperopic refractive errors.[7-9,15,21] That this was not the case in Northern Ireland implies that there may be separate regulation of axial elongation leading to myopia as compared to axial elongation leading to reduction in hyperopia, as appears to be the case earlier in development.[46,47]

While little is known about why some children remain significantly hyperopic, the development of myopia may be associated with increased engagement in education.[59-67] However, surveys carried out by the Organisation for Economic Co-operation and Development suggest that educational outcomes are higher in Australia[68] than in the United Kingdom, including Northern Ireland.[69] In support of this, our results showed that the proportion of parental tertiary education was significantly lower in Northern Ireland than Sydney.

Previous studies have also reported a strong link between parental myopia and the development of myopia in children.[33,35] While parental myopia was again a strong predictor of refraction in these two samples of children, this factor only accounted for between 2% and 3% of variation in refractive error in pooled data. In general, the differences in levels of parental myopia between the two sites were small and cannot account for the considerable differences in myopia prevalence between sites.

Another factor that has been documented is the protective effect against the development of myopia of increased time spent outdoors,[34,70-73] which has been shown to be mediated by increased release of retinal dopamine by bright light in animal models.[74,75] A previous analysis of Chinese children growing up in Singapore and Sydney has shown that the major factor associated with the large difference in prevalence of myopia is time spent outdoors.[2] The authors do not currently have data on time spent outdoors from Northern Ireland and Sydney, but comparable data will be available from phase 2 of the NICER study, which is reexamining participants three years after their initial measures. However, weather records suggest that climate in Northern Ireland may place an upper limit on light exposures of 2 hours of sunlight per day for 4 months of the year,[76] which is probably below that required for protection,[34,70] whereas daily sunshine duration is typically 6 to 7 hours year round in Sydney.[77] National Aeronautics and Space Administration data also suggest that illumination is generally lower in Northern Ireland than in Sydney.[78] These two aspects of light exposure may contribute to the higher levels of myopia in Northern Ireland, and the difference in

availability of bright sunlight exposure in the two locations makes such a hypothesis plausible. It will be tested through the collection of individual data on time spent outdoors in future follow-up studies.

There are many other differences between the two sites. The authors have dealt with four (educational and outdoor exposures in the children and parental myopia and education), because there is substantial evidence that they have a major impact on the development of myopia, and there are plausible mechanisms for their effects. The evidence for other factors is weaker. Diet has been suggested as a risk factor for myopia, with a plausible mechanism proposed,[79] but in Singapore children, while diet does appear to influence axial length, it has no effect on refraction, presumably owing to effective emmetropization.[80] Even extreme undernutrition, resulting in overall stunting, does not appear to influence refractive development.[81] The authors do not have systematic data on this very complex factor, but the available evidence suggests that it is unlikely to explain the differences. Population density may also be important, as suggested in two previous studies.[82,83] Both articles suggest that the prevalence of myopia is higher when the population density is high, but the data from China[83] show that, while the association is statistically significant, the impact of population density is very small. This is also the case for the data from Sydney.[82] It should also be noted that the SMS sample is predominantly urban, while the NICER study surveyed urban and rural areas; yet the prevalence of myopia was higher in Northern Ireland. The population density is 130 persons/km^2 for Northern Ireland,[84] compared to 2058 persons/km^2 in Sydney,[85] suggesting that population density is unlikely to explain the higher prevalence in Northern Ireland.

The prevalence of astigmatism is also much lower in Sydney than in Northern Ireland. One possible explanation for the difference is based on the higher prevalence of ametropia in Northern Ireland, which has been previously reported to be related to a higher prevalence of astigmatism.[86-88] This can be ruled out, since Figure 3 shows that for emmetropia or any given level of ametropia, there is less astigmatism in Sydney than in Northern Ireland. There is some evidence for the presence of a developmental process by which refractive astigmatism is reduced relative to corneal astigmatism.[86,87] While this process is poorly characterized, the higher levels of astigmatism in Northern Ireland, which are consistent with corneal measures,[88] indicate that this process may be less effective in Northern Ireland. It is to be noted that levels of astigmatism also vary between other populations of European ancestry.[89,90] Further work is required to fully explore the mechanisms underlying the control of the development of astigmatism.

In summary, this comparison of refractive status in two age- and ethnicity-matched school-based representative samples of children of European ancestry from Northern Ireland and Sydney, using common methodology, showed that children in Northern Ireland had a significantly higher prevalence of both myopia and hyperopia, as well as astigmatism, at both ages 6 to 7 years and 12 to 13 years, than did children in Sydney. The authors suggest that the differences in the development of myopia may be explained by the protective effect of time spent outdoors in bright light, but the mechanisms that account for the disparities in hyperopia and astigmatism are currently unclear.

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