Refractive and Corneal Astigmatism in White School Children in Northern Ireland

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PURPOSE. To study the prevalence of and relation between refractive and corneal astigmatism in white school children in Northern Ireland and to describe the association between refractive astigmatism and refractive error.

METHODS. Stratified random clustering was used to recruit 1053 white children, 392 aged 6–7 years and 661 aged 12–13 years. Eye examinations included cycloplegic autorefraction and ocular biometric measures of axial length and corneal curvature.

RESULTS. The prevalence of refractive astigmatism (≥1 DC) did not differ significantly between 6- to 7-year-old children (24%; 95% confidence interval [CI], 19–30) and 12- to 13-year-old children (20%; 95% CI, 14–25). The prevalence of corneal astigmatism (≥1 DC) also did not differ significantly between 6- to 7-year-old children (29%; 95% CI, 24–34) and 12- to 13-year-old children (25%; 95% CI, 21–28). While levels of refractive astigmatism and corneal astigmatism were similar, refractive astigmatism was predominantly oblique (76%; 95% CI, 67–85, of 6- to 7-year-olds; 59%; 95% CI, 48–70, of 12- to 13-year-olds), but corneal astigmatism was predominantly with-the-rule (80%; 95% CI, 72–87, of 6- to 7-year-olds; 82%; 95% CI, 74–90, of 12- to 13-year-olds). The prevalence of refractive astigmatism was associated with increasing myopia and hyperopia.

CONCLUSIONS. This study is the first to provide robust population-based data on the prevalence of astigmatism in white school children in the United Kingdom. The prevalence of refractive astigmatism and corneal astigmatism is stable between 6 and 7 years and 12 and 13 years, although this finding would need to be confirmed by prospective studies. There is a high prevalence of refractive and corneal astigmatism which is associated with ametropia. (*Invest Ophthalmol Vis Sci.* 2011; 52:4048–4053) DOI:10.1167/iovs.10-6100

Astigmatism is a clinically important condition[1]: it is associated with reduced visual acuity[2] and an increased risk of developing refractive amblyopia.[3,4] Furthermore, amblyopia treatment may be influenced by the orientation of the axis of astigmatism.[5] Two components of astigmatism can currently be independently measured: refractive astigmatism and corneal astigmatism, with the difference between these being due to internal astigmatism. Due to the effect of internal astigmatism, the magnitude of corneal astigmatism is generally greater than that of refractive astigmatism.[6,7]

Although there have been numerous reports on the prevalence of refractive astigmatism in school children, studies on populations of children with European ancestry have given divergent data with a prevalence of 26%[8] in the United States compared with 6.7% in Australia[9] and 5.2% in Sweden,[10] and few studies are available on the prevalence and distribution of either refractive or corneal astigmatism in UK or Irish school children.

As the population of Northern Ireland is ethnically homogenous (99% white),[11] the purpose of the present study is to describe the prevalence of refractive astigmatism in white school children, facilitating comparisons with other population-based surveys examining school-age children of predominantly European origin in Europe, Australia, and the United States. The association between the spherical component of the refraction and presence of refractive astigmatism is also described, together with the relationship between refractive and corneal astigmatism.

METHODS

Subjects

The Northern Ireland Childhood Errors of Refraction (NICER) study is a population-based survey of school children aged 6–7 years and 12–13 years living in Northern Ireland. It is a sister study of the Aston Eye Study examining refractive error in a multiethnic urban population (Logan NS. *IOVS* 2008;49:ARVO E-Abstract 2602). The study was approved by the University of Ulster Research Ethics Committee, and the conduct of the study adhered to the tenets of the Declaration of Helsinki. After an explanation of the nature and possible consequences of the study, written consent was obtained from the parents or guardian of all children before the examination. The 12- to 13-year-old children also gave written consent, and verbal assent was obtained from the 6- to 7-year-old children.

The study methods have previously been described in detail.[12] In brief, stratified random sampling of schools from geographic areas characteristic of Northern Ireland was used to obtain a representative sample of schools and children from urban/rural and deprived/nondeprived areas. Within individual schools, all children in one or more classes were invited to participate. In line with the Sydney Myopia Study (SMS),[13] the protocol for data collection included cycloplegic autorefraction (1% cyclopentolate hydrochloride, Minims single dose; Chauvin Pharmaceuticals, Romford, UK) using a binocular open-field autorefractor (SRW-5000; Shin-Nippon, Tokyo, Japan). At least five measurements were taken with the representative value as determined by the instrument used in subsequent analyses. This autorefractor permits reliable measures of both the spherical and cylindrical (±0.24 D SD) components of refraction.[14] The ocular biometer (Zeiss IOLMaster; Carl Zeiss Meditec, Oberkochen, Germany) was used to take at

least three measures of axial length and corneal curvature and five simultaneous measures of anterior chamber depth. The 95% limits of agreement of the ocular biometer are ±0.04 mm for mean corneal curvature measures,[15] (which approximates to ±0.22 D). Participants were tested within school premises during the school day, between May 2006 and March 2008.

Data Analysis and Definitions

Refractive astigmatism has been taken from the autorefractor result (absolute cylindrical value), and corneal astigmatism is defined as the difference between the flattest and steepest corneal meridians with the cylindrical axis set along the flattest meridian. The prevalence of astigmatism of ≥1.00, ≥1.50, and ≥2.00 DC is reported.

The spherical value of the autorefractor result (written in negative cylindrical form) has been used to present data on the variation of the presence of refractive astigmatism of at least 1.00 DC with refractive error. To classify astigmatism, with-the-rule (WTR) astigmatism is defined as a negative cylinder axes from 1° to 15° and from 165° to 180°, against-the-rule (ATR) astigmatism as a negative cylinder axes between 75° and 105° and oblique astigmatism as axes from 16° to 74° or from 106° to 164°. Although these definitions were chosen to facilitate comparisons with other studies,[3,9] there is widespread variation in the classification of WTR, ATR, and oblique astigmatism across previous studies.[16]

As refractive and corneal astigmatism are correlated between the right and left eyes (Spearman correlation refractive astigmatism 0.36, corneal astigmatism 0.60; both $P < 0.001$) only data from the right eye are presented. To fully describe the relationship between refractive and corneal astigmatism the cylinders and their axes were converted into vectors.[17] A positive J_0 indicates WTR astigmatism and a negative J_0 indicates ATR astigmatism. A positive J_{45} indicates the power is greatest at 135°, and a negative J_{45} indicates that power is greatest at 45°. Spherical equivalent refraction (SER) is defined as the sphere + ½ cylinder.

Statistical Analysis

All statistical analyses were carried out using commercially available software (Intercooled Stata 9.2; StataCorp, College Station, TX). As the distributions of refractive and corneal astigmatism are skewed toward lower levels of astigmatism, the median, interquartile ranges (IQR) and Spearman correlations have been used. Mann-Whitney U test (equivalent to the Wilcoxon rank sum test) was used to compare median levels of astigmatism by age. Prevalence estimates with 95% confidence intervals allowing for clustering of children within schools are presented. Here χ^2 tests have been used to investigate age-group differences in both the prevalence of astigmatism (using three cutoffs: at least 1 DC, at least 1.5 DC, or at least 2DC) and prevalence of axes classification of astigmatism (WTR, ATR, or oblique). Kruskall-Wallis one-way analysis of variance was used to examine whether the median level of the spherical component of refraction and SER varied according to the axes classification of astigmatism. Results are considered statistically significant if $P < 0.05$.

RESULTS

Participants

Of the children invited to participate in the study, parental consent was obtained from 65% of 12- to 13-year-olds and 62% of 6- to 7-year-olds. Reflective of the Northern Irish population, 98.7% of participants were white, and this report presents data from 661 white children aged 12-13 years (50.5% male) and 392 white children aged 6–7 years (49.5% male). The mean ages of the two study groups were 13.1 years (range, 12.1–14.1) and 7.1 years (range, 6.3–7.8), respectively.

## The Distribution and Prevalence of Refractive and Corneal Astigmatism

The prevalence of refractive astigmatism (≥1 DC) was 24% (95% CI, 19–30) in 6- to 7-year-old children and 20% (95% CI, 14–25) in 12- to 13-year-old children (Fig. 1). The prevalence of corneal astigmatism (≥1 DC) was 29% (95% CI, 24–34) in 6- to 7-year-old children and 25% (95% CI, 21–28) in 12- to 13-year-old children (Fig. 1). There are no statistically significant differences in the prevalence (≥1 DC, $\chi^2 = 3.13$) or median level ($z = 1.8$) of refractive astigmatism between the 6- to 7-year-old children (median 0.50 DC, IQR 0.25) and the 12- to 13-year-old children (median 0.50 DC, IQR 0.50) or in the prevalence (≥1 DC, $\chi^2 = 2.4$) or median level ($z = 1.9$) of corneal astigmatism (6- to 7-year-old children, median 0.73 DC, IQR 0.55; 12- to 13-year-old children, median 0.58 DC, IQR 0.70).

The Distribution of the Axes of Refractive and Corneal Astigmatism

There was no statistically significant age group difference in the prevalence of WTR, ATR, or oblique refractive or corneal astigmatism (all $\chi^2 > 0.1$). Although most refractive astigma-
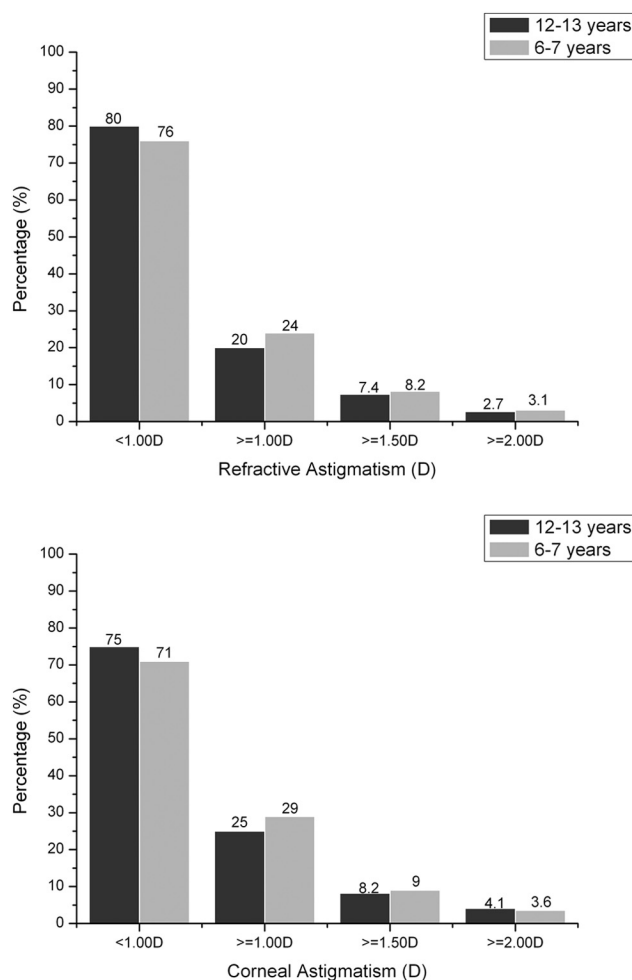
FIGURE 1. Prevalence of refractive and corneal astigmatism. Refractive astigmatism assessed using cycloplegic autorefraction; corneal astigmatism assessed using ocular biometer corneal curvature measures. Here 6- to 7-year-old children, $n = 392$; 12- to 13-year-old children, $n = 661$. For all three levels of astigmatism, there were no statistically significant age group differences in the prevalence of refractive (all $\chi^2 > 0.1$) or corneal astigmatism (all $\chi^2 > 0.1$).

6-7-year-old children

12-13-year-old children
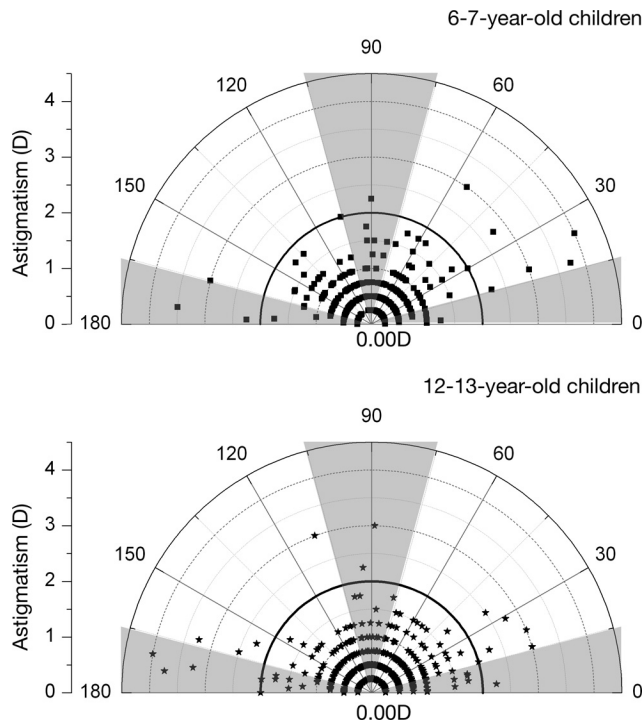
FIGURE 2. Polar plots of refractive astigmatism. Refractive astigmatism assessed using cycloplegic autorefraction. 6- to 7-year-old children, $n = 392$; 12- to 13-year-old children, $n = 661$. D, diopters. The *rings* represent the magnitude of the astigmatism: the innermost point is 0 DC, with a step size between rings of 0.50 DC. The *solid black line* indicates 2 DC. The angles range from 0° to 180° and correspond to the range of angles for astigmatism.[18] The *shaded areas* show WTR and ATR astigmatism. Here 8.4% ($n = 33$) of 6- to 7-year-olds and 10.3% ($n = 68$) of 12- to 13-year-olds have refractive astigmatism <0.25 DC.

tism (≥1.00 DC) was classified as oblique (6- to 7-year-old children, 76% CI, 67–85; 12- to 13-year-old children, 59% CI, 48–70), most corneal astigmatism (≥1.00 DC) was WTR (6- to 7-year-old children, 80% CI, 72–87; 12- to 13-year-old children, 82% CI, 74–90). However, as this classification of astigmatism into WTR, ATR, and oblique is rather arbitrary, polar plots have been used to better illustrate the distribution of the axes of both refractive and corneal astigmatism. Polar plots also display the relationship between the magnitude and the axis of astigmatism. Figure 2 illustrates that most refractive astigmatism is <2.00 DC and shows the even distribution of the axes of RA. Figure 3 shows that most corneal astigmatism is also <2 D.

The Relationship between Refractive Astigmatism and Refractive Error

There is a statistically significant association between greater amount of refractive astigmatism and the absolute value of spherical refraction (Spearman correlation: 6- to 7-year-old children, 0.23; 12- to 13-year-old children, 0.32). Figure 4 illustrates that the presence of refractive astigmatism of at least 1 D increases with spherical error (both myopia and hyperopia) in 12- to 13-year-old children and with hyperopia in 6- to 7-year-old children. There is a low prevalence of myopia (of at least −0.50 DS SER) in 6- to 7-year-old children (2.0% CI, 0.4–3.6) compared with 12- to 13-year-old children (15.0% CI, 10.7–19.3).

There is no statistically significant difference in the median level of the spherical component of refraction or SER by axis classification (WTR, ATR, or oblique) in 6- to 7-year-old or 12- to 13-year-old children (all Kruskall-Wallis > 0.2).

The Relationship between Corneal and Refractive Astigmatism

Figure 5 illustrates the association between corneal and refractive J_0 and J_{45} astigmatism in 12- to 13-year-old children. Although corneal and refractive measures of J_{45} (oblique) astigmatism are similar, the magnitude of refractive J_0 (regular) astigmatism is lower than corneal J_0. Similar associations were found in the 6- to 7-year-old age group (graphs not shown).

DISCUSSION

Refractive Astigmatism

This is the first study to describe the prevalence of refractive astigmatism and its relationship with refractive error in a UK population. Although refractive astigmatism has been shown to change considerably throughout infancy,[19,20] our data support previous reports (both cross-sectional and longitudinal)[8,9,16,21] from other countries showing that refractive astigmatism is relatively stable throughout later childhood (5–15 years approximately). However, other studies have reported that the prevalence of refractive astigmatism increases[22–24] or decreases[25] with age. The type of astigmatism may determine how it changes with age with reports of myopic astigmatism increasing and hyperopic astigmatism decreasing with age[26,27] and increases in the prevalence of lower amounts of astigmatism (≥0.75 DC) but not higher amounts of astigmatism (≥2.00 DC) throughout childhood.[22,24]

6-7-year-old children

12-13-year-old children
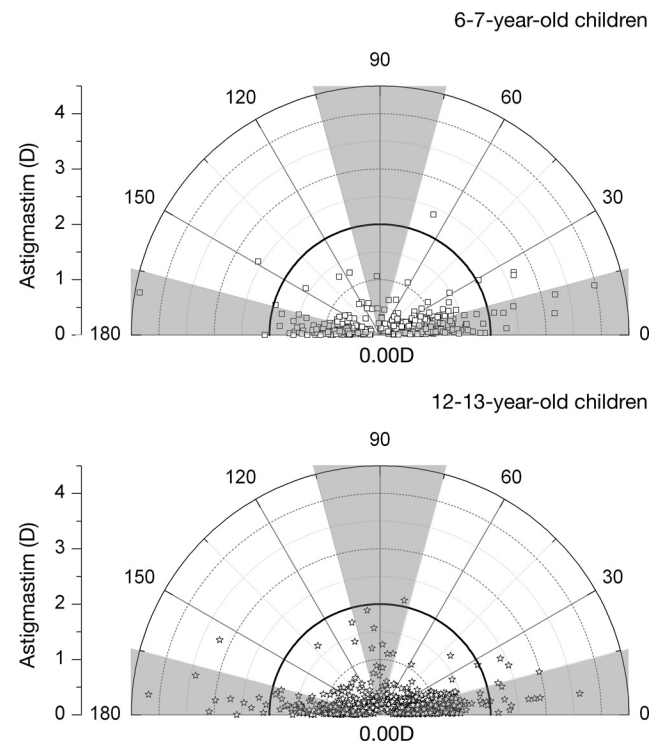
FIGURE 3. Polar plots of corneal astigmatism. Corneal astigmatism assessed using the ocular biometer. Here 6- to 7-year-old children, $n = 392$; 12- to 13-year-old children, $n = 661$. D, diopters. The *rings* represent the magnitude of the astigmatism: The innermost point is 0 DC, with a step size between rings of 0.50 DC. The *solid black line* indicates 2 DC. The angles range from 0° to 180° and correspond to the range of angles for astigmatism.[18] The *shaded areas* show WTR and ATR astigmatism. Here 6.6% ($n = 26$) of 6- to 7-year-olds and 10.6% ($n = 70$) have corneal astigmatism <0.25 DC.
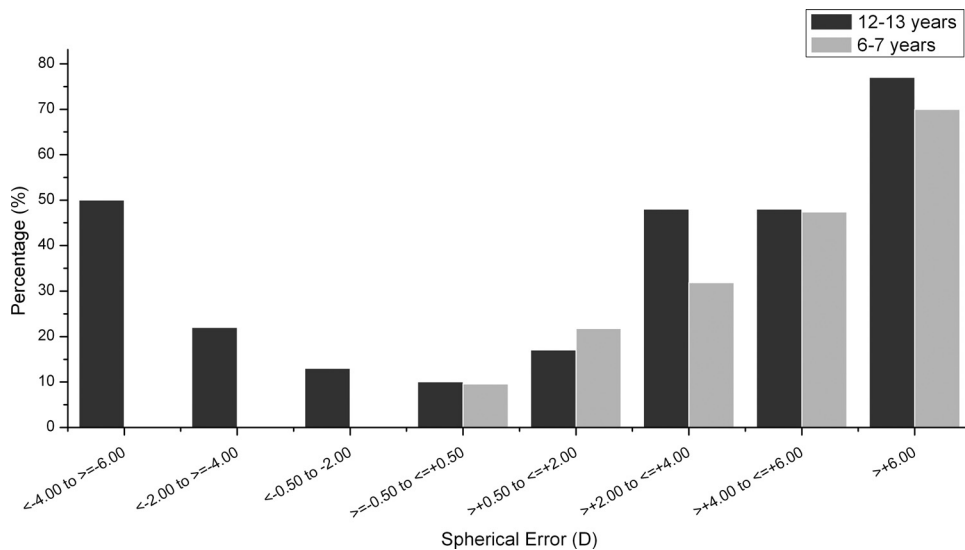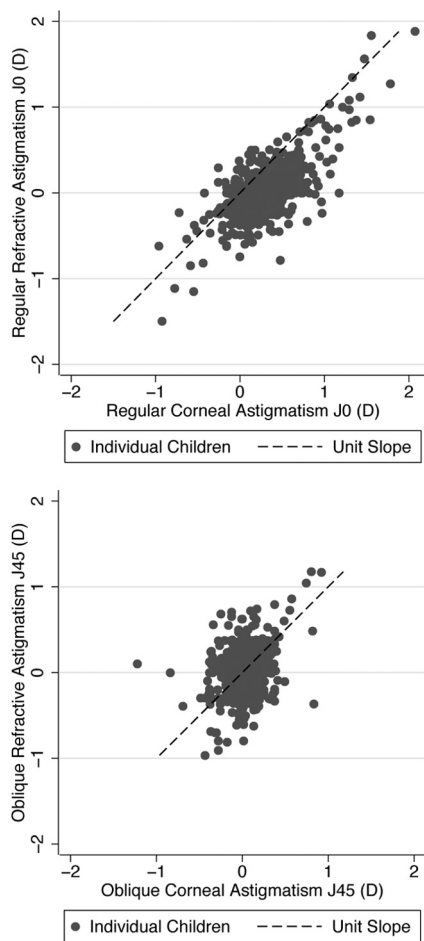
FIGURE 4. Distribution of refractive astigmatism of at least 1 D by classification of spherical error. 6- to 7-year-old children, $n = 392$; 12- to 13-year-old children, $n = 661$. Spherical error assessed by cycloplegic autorefraction, with the result recorded in minus cylindrical form.

The prevalence of refractive astigmatism ≥1.00 DC in the present study (6- to 7-year-olds, 24% 95% CI, 18–30; 12- to 13-year-olds, 20% 95% CI 14–25) is much higher than that reported by the SMS in a largely white Australian population

FIGURE 5. Relationship between corneal and refractive J_0 and J_{45} values (12- to 13-year-old children). Twelve- to 13-year-old children, $n = 661$. J_0, regular astigmatism; J_{45}, oblique astigmatism. Corneal astigmatism assessed with the ocular biometer; refractive astigmatism assessed with cycloplegic autorefraction.

(12-year-olds, 6.7%; 6-year olds, 4.8%).[9] However, the prevalence of refractive astigmatism in the UK NICER study is considerably lower when higher levels of astigmatism are considered (Fig. 1). The difference in the prevalence of refractive astigmatism between white school children in Australia in the SMS and those in the UK NICER study appears to be largely due to an increased prevalence of astigmatism of at least 1 D but less than 2 D. These differences in the prevalence of refractive astigmatism may be associated with the different prevalence of ametropia in the two countries. In the UK NICER study the prevalence of ametropia (both myopia and moderate hyperopia) in 12- to 13-year-old children is of the order of three times greater than that reported for white children in Australia in the SMS.[28]

The prevalence of refractive astigmatism in the present study is more in line with the 26% prevalence of at least 1.00 DC reported in white children (age 5 to 17 years) in the United States,[8] where the prevalence of refractive astigmatism was also considerably lower (13.1%) when the definition was amended to at least 1.25 DC. Other European data from Sweden[10] and Poland[29] demonstrate lower prevalence rates compared with the United States or the UK NICER study. However both the Swedish and Polish studies used retinoscopic rather than autorefractor measures, and in many studies that have reported astigmatism using both techniques the prevalence of astigmatism is higher where autorefraction has been used.[23–25,30]

The widely reported differences in the prevalence of refractive astigmatism in white populations may reflect either genetic differences among white populations in different geographical locations or variations in environmental influences.

The Distribution of the Axes of Refractive Astigmatism

In the present study, across both age groups, most refractive astigmatism is classified as oblique, replicating the findings in Australian school children in the SMS. In contrast some studies using retinoscopy have reported that most refractive astigmatism in children aged 6 years is WTR.[21,31,32]

Both the current NICER study and the Australian SMS[9] have used a broad definition of oblique astigmatism. Cowen and Bobier[33] classified astigmatism as oblique in 15% of preschool Canadian children using a definition of oblique astigmatism as 31°–60° and 121°–150°, considerably narrower than the definition used in the present study. Using this definition the

prevalence of oblique astigmatism in the present study reduces from 76% to 43% in 6- to 7-year-olds with astigmatism (≤1 DC) and from 59% to 23% of astigmatic 12- to 13-year-olds. Abrahamsson and Sjostrand[34] have suggested that the presence of oblique astigmatism is subject to substantial geographical variations and have described oblique astigmatism as especially amblyogenic. However, the polar plots of the present study's data suggest that the axes of refractive astigmatism are evenly distributed, with the axes of higher levels of astigmatism closer to the horizontal and vertical axes rather than oblique, therefore possibly reducing the risk of astigmatic amblyopia.

Refractive Astigmatism and Refractive Error

Although it has been previously reported that hyperopic eyes are more likely to be astigmatic than myopic eyes[35–37] and other studies have described an association between refractive astigmatism and myopia,[19,38] the present study reports that the prevalence of refractive astigmatism in 12- to 13-year-old children increases with both increasing myopia and hyperopia. This association between ametropia and astigmatism supports that astigmatic blur in early life may impact on emmetropization,[37] and studies describing the relation between refractive astigmatism and refractive error need to consider the prevalence of myopia and hyperopia in the population.

Although astigmatic refractive error does not differ between the two age groups, this does not preclude changes in astigmatic errors of individuals during childhood. Prospective studies are required to further evaluate the relationship between refractive astigmatism and refractive error development and environmental versus genetic influences.

Corneal Astigmatism and Its Relation with Refractive Astigmatism

The prevalence of corneal astigmatism (≥1.00 DC) in the UK NICER study (6- to 7-year-olds, 29%; 12- to 13-year-olds, 25%) is also higher than that reported in white Australian children by the SMS[9] (6- to 7-year-olds, 22%[39]; 12- to 13-year-olds, 19%). The NICER study confirms previous reports that corneal astigmatism exceeds refractive astigmatism,[9,39–41] and the higher levels of refractive astigmatism compared with Australian school children in the SMS appears to be due to the higher level of corneal astigmatism.

Future studies should try to establish if risk factors for astigmatism are genetic, environmental or a combination of both. Prospective studies from infancy would be of help in identifying whether factors contributing to astigmatism occur before the onset of ametropia or as a consequence of it.

Limitations

Due to ethical constraints, the authors were unable to determine reasons for nonparticipation in the study.

CONCLUSIONS

This is the first epidemiologic study to describe the prevalence of refractive and corneal astigmatism in a Northern Irish population: There is a high prevalence of both refractive and corneal astigmatism in white children in Northern Ireland, and refractive astigmatism is associated with both myopia and hyperopia. Both refractive and corneal astigmatism are relatively stable between the ages of 6–7 and 12–13 years. The high prevalence of refractive astigmatism has important implications for service planning due to the association between refractive astigmatism and amblyopia.

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