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Ocular biometry, refraction and time spent outdoors during daylight in Irish schoolchildren

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Background: Previous studies have investigated the relationship between ocular biometry and spherical equivalent refraction in children. This is the first such study in Ireland. The effect of time spent outdoors was also investigated.

Methods: Examination included cycloplegic autorefractometry and non-contact ocular biometric measures of axial length, corneal radius and anterior chamber depth from 1,626 children in two age groups: six to seven years and 12 to 13 years, from 37 schools. Parents/guardians completed a participant questionnaire detailing time spent outdoors during daylight in summer and winter.

Results: Ocular biometric data were correlated with spherical equivalent refraction (axial length: $r = -0.64$, corneal radius: $r = 0.07$, anterior chamber depth: $r = -0.33$, axial length/corneal radius ratio: $r = -0.79$, all $p < 0.0001$). Participants aged 12–13 years had a longer axial length (6–7 years 22.53 mm, 12–13 years 23.50 mm), deeper anterior chamber (6–7 years 3.40 mm, 12–13 years 3.61 mm), longer corneal radius (6–7 years 7.81 mm, 12–13 years 7.87 mm) and a higher axial length/corneal radius ratio (6–7 years 2.89, 12–13 years 2.99), all $p < 0.0001$. Controlling for age: axial length was longer in boys (boys 23.32 mm, girls 22.77 mm), and non-White participants (non-White 23.21 mm, White 23.04 mm); corneal radius was longer in boys (boys 7.92 mm, girls 7.75 mm); anterior chamber was deeper in boys (boys 3.62 mm, girls 3.55 mm, $p < 0.0001$), and axial length/corneal radius ratios were higher in non-White participants (non-White 2.98, White 2.94, $p < 0.0001$). Controlling for age and ethnicity, more time outdoors in summer was associated with a less myopic refraction, shorter axial length, and lower axial length/corneal radius ratio. Non-White participants reported spending significantly less time outdoors than White participants ($p < 0.0001$).

Conclusion: Refractive error variance in schoolchildren in Ireland was best explained by variation in the axial length/corneal radius ratio with higher values associated with a more myopic refraction. Time spent outdoors during daylight in summer was associated with shorter axial lengths and a less myopic spherical equivalent refraction in White participants. Strategies to promote daylight exposure in wintertime is a study recommendation.

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Recent epidemiological studies involving children reported that spherical equivalent refraction (SER) distribution varies with ethnicity,¹ location,² and environmental factors such as daylight exposure.^{3,4} Longer axial lengths are associated with myopic eyes with consequently increased odds of pathological myopia.⁵ Moreover, an association between axial elongation, myopia progression, and reduced time outdoors has been reported in several studies.^{6,7} For example, axial elongation and myopia progression are reportedly slower in summer than in winter in Danish

and Chinese children,^{8,9} and young Australian adults.¹⁰

With half of the population of the world projected to be myopic by 2050,¹¹ and a confluence of studies in support of the inverse relationship between light exposure and myopia development,^{3,6,8} there has been a focus by researchers to examine the impact of daylight exposure on ocular development in children. However, there is a paucity of contemporary population-based age norms for ocular biometric measures in northern European schoolchildren, and in particular, their relationship with refractive

data and environmental factors such as daylight. As daylight is a natural light source, with a continuous spectral power distribution covering the full visible range, its attributes alter with geographical location and season, in particular day-lengths, and variations in light intensity with fluctuating weather conditions.¹² Furthermore, seasonal changes in ambient light exposure and axial length and SER changes have been previously reported.^{4,10}

In this context, understanding the relationships between ocular biometric parameters, refractive status and seasonal light

exposure are important in the Republic of Ireland (henceforth Ireland) where there is considerable variation in day length (7.5 hours in winter to 17 hours in summer),¹³ and as significant levels of refractive error exist.¹⁴ Notably, the Ireland Eye Study (present study) findings for myopia prevalence (6–7 years 3.3 per cent, 12–13 years 19.9 per cent) were broadly in line with the Northern Ireland Childhood Errors of Refraction (NICER) study in the UK (6–7 years 2.8 per cent, 12–13 years 17.7 per cent).¹⁴ In comparison, significantly lower levels of myopia were reported in the Sydney Myopia Study (six years 1.6 per cent, 12 years 12.8 per cent).²

French et al. postulated one reason for the significantly lower myopia prevalence in the Sydney Myopia Study might be due to the difference in daylight exposure, as bright sunlight exposure is greater in Sydney, particularly in winter, when compared to Northern Ireland (UK).² Epidemiological longitudinal studies reported time outdoors may prevent or delay the onset of myopia.^{15,16} Furthermore, clinical trials in Asia found increased time outdoors was associated with a reduced incidence of myopia,^{17,18} and less myopic shift in refraction.^{3,19} However, the precise biological mechanisms which underpin the protective effect of time spent outdoors against myopia remain unclear; theories include light exposure, depth of focus and dopamine release in the retina.^{20–22}

This paper is the first to report the distribution of ocular biometric parameters, and their relationship with SER status and time outdoors during daylight in both summer and winter in schoolchildren in Ireland.

Methods

The Technological University Dublin Research Ethics Committee granted ethics approval, and the study was carried out in compliance with the tenets of the Declaration of Helsinki.

Data collection was conducted between June 2016 and January 2018; the methodology and study response rate were previously described.¹⁴ This study involved 1,626 participants in Ireland: 728 participants aged 6–7 years (377 boys and 351 girls) and 898 participants aged 12–13 years (504 boys and 394 girls).

The study protocol included cycloplegic autorefractometry (Dong Yang Reiko ORK 11

Auto Ref-Keratometer; Everview Corp., Seoul, Korea) to determine the refractive error. In order to produce adequate cycloplegia with minimum systemic side effects, one drop of topical anaesthetic (Minims proxymetacaine hydrochloride 0.5% w/v; Bausch & Lomb, Kingston upon Thames, UK), was followed by one drop of cyclopentolate hydrochloride (Minims 1% w/v; Bausch & Lomb) for White participants; non-White participants were administered two drops of cyclopentolate hydrochloride five minutes apart. While a single drop of 1% cyclopentolate hydrochloride has been reported to produce adequate cycloplegia when compared to using two or three drops,²³ two drops of cyclopentolate hydrochloride were found more effective for hyperopic South Asian participants with dark irides.²⁴

Once it was established cycloplegia had been achieved (pupillary reactions non-responsive to light and accommodation amplitude less than 2D on push-up test), at least 20 minutes after instillation of the eye-drops, autorefractometry was carried out. The representative value for SER – sphere plus half the cylindrical value – was used in subsequent analysis.

The Zeiss IOLMaster 500 (Carl Zeiss, Meditec Inc., Jena, Germany) was used to measure axial length (three measurements), anterior chamber depth (five measurements) and corneal radius (three measurements). The mean corneal radius was calculated as the average of the steepest and flattest corneal radius. The axial length/corneal radius ratio was defined as the axial length divided by the mean corneal radius.

Parents/legal guardians of participants completed a standardised lifestyle questionnaire (previously described),²⁵ reporting inter alia, time outdoors during daylight hours in summer and in winter; the response options were as follows: less than one hour; one to two hours; two to four hours; or more than four hours.

The study co-ordinator assessed participant ethnicity and confirmed using the parent/guardian self-report. Participants were categorised as either White (88 per cent), or non-White (11 per cent) (Black five per cent, East Asian three per cent, South Asian two per cent and Arab one per cent subjects combined).

Statistical methodology

Data were analysed using the Statistics Package for Social Sciences version 24.0 (IBM, Armonk, NY, USA).

Analysis of the distribution of SER, and biometrics involved were undertaken using descriptive statistics (mean, standard error of mean, standard deviation of the mean, median, range). Measures of skewness and kurtosis were calculated for distributions. Distributions for SER and ocular biometric measures were tested for normality using the Kolmogorov–Smirnov test and were considered normal when $p > 0.05$ (Table 1). Linear regression models were constructed to assess the effect of age, ethnicity and gender on the distribution of SER and biometric parameters.

Correlations between SER and biometric measures were calculated with Pearson correlation analysis. Linear regression models were created to examine the relationships between biometric parameters and SER while controlling for age, and ethnicity. The regression co-efficient (B) and the 95 per cent confidence interval for B were calculated.

Time spent outdoors in summer and winter data satisfied the assumptions required to perform multinomial logistic regression. The relationship between time spent outdoors with age, ethnicity and gender was examined using logistic regression analysis, with participants reporting over four hours outdoors in daylight as the reference category. Controlling for age and ethnicity, general linear models were applied to examine the relationship between time outdoors during daylight and SER, and time outdoors during daylight and ocular biometric parameters.

The right and left eyes were significantly correlated for SER and ocular biometric measures (Pearson correlation: SER $r = 0.89$, axial length $r = 0.95$, corneal radius $r = 0.96$, anterior chamber depth $r = 0.96$, axial length/corneal radius $r = 0.89$, all $p < 0.0001$); therefore, results are presented for the right eye only. The five per cent level of significance was used throughout. Confidence intervals were 95 per cent.

Results

Table 1 presents descriptive statistics, including measures of spread, of SER, and ocular biometric parameter measures by age, gender and ethnicity for study participants. The distribution for SER was non-normal. Ocular biometric measures were in the main normally distributed for the population overall with some exceptions in sub-groups (see the final column in Table 1).

	Mean	SEM	SD	Median	Range Min, max	Kurtosis	Skewness	K-S
Spherical equivalent (D)								
6–7 years (n = 728)	1.44 [†]	0.05	1.25	1.25	–4.50, 9.00	6.09	1.62	< 0.0001
12–13 years (n = 898)	0.38	0.05	1.61	0.50	–10.25, 8.25	5.88	–0.50	< 0.0001
Boys (n = 881)	0.90 [‡]	0.05	1.52	0.75	–5.00, 8.00	3.73	0.48	< 0.0001
Girls (n = 745)	0.80	0.06	1.59	0.75	–10.25, 9.00	8.00	–0.52	< 0.0001
White (n = 1,441)	0.96	0.04	1.49	0.75	–5.00, 9.00	4.61	0.56	< 0.0001
Non-White (n = 185)	0.00 [§]	0.41	1.78	0.25	–10.25, 3.00	7.74	–0.22	< 0.0001
Axial length (mm)								
6–7 years (n = 728)	22.53 [†]	0.03	0.79	22.52	19.24, 25.73	0.93	–0.15	0.20
12–13 years (n = 898)	23.50	0.03	0.89	23.46	20.37, 27.65	0.98	0.25	0.01
Boys (n = 881)	23.32 [‡]	0.03	0.95	23.35	19.14, 26.47	0.64	0.01	0.20
Girls (n = 745)	22.77	0.03	0.92	22.75	19.69, 27.65	1.56	0.37	0.01
White (n = 1,441)	23.05	0.03	0.95	23.04	19.69, 26.27	0.38	0.15	0.20
Non-White (n = 185)	23.21 [§]	0.08	1.11	23.26	19.14, 27.66	1.64	0.26	0.20
Corneal radius (mm)								
6–7 years (n = 728)	7.81 [†]	0.01	0.27	7.80	7.10, 8.69	0.05	0.27	0.20
12–13 years (n = 898)	7.87	0.01	0.26	7.87	6.95, 8.71	0.22	–0.05	0.20
Boys (n = 881)	7.92 [‡]	0.01	0.26	7.92	7.10, 8.71	0.08	0.05	0.20
Girls (n = 745)	7.75	0.01	0.25	7.75	6.76, 8.68	0.20	0.11	0.20
White (n = 1,441)	7.85	0.01	0.27	7.84	7.09, 8.71	0.08	0.12	0.10
Non-White (n = 185)	7.80	0.02	0.27	7.83	6.95, 8.45	–0.22	–0.18	0.20
Axial length/corneal radius								
6–7 years (n = 728)	2.89	0.003	0.09	2.89	2.50, 3.24	1.79	–0.36	0.20
12–13 years (n = 898)	2.99 [†]	0.004	0.11	2.98	2.59, 3.56	2.11	0.43	0.01
Boys (n = 881)	2.95	0.004	0.11	2.95	2.59, 3.39	1.05	0.07	0.01
Girls (n = 745)	2.94	0.004	0.11	2.93	2.50, 3.56	2.74	0.63	0.01
White (n = 1,441)	2.94	0.001	0.11	2.94	2.50, 3.39	1.29	0.15	0.01
Non-White (n = 185)	2.98 [§]	0.01	0.12	2.95	2.73, 3.56	3.32	1.28	0.01
Anterior chamber depth (mm)								
6–7 years (n = 728)	3.40	0.02	0.21	3.40	2.45, 3.91	3.31	–0.81	0.05
12–13 years (n = 898)	3.61 [†]	0.01	0.25	3.62	2.26, 4.33	2.62	–0.67	0.07
Boys (n = 881)	3.63 [‡]	0.01	0.26	3.63	2.26, 4.33	3.84	–0.94	0.02
Girls (n = 745)	3.55	0.01	0.25	3.55	2.45, 4.26	0.70	–0.24	0.02
White (n = 1,441)	3.60	0.01	0.26	3.61	2.26, 4.33	2.49	–0.67	0.10
Non-White (n = 185)	3.54	0.02	0.23	3.53	2.85, 4.08	0.12	–0.13	0.20

D: dioptre, K-S: Kolmogorov–Smirnov test for normality, max: maximum, min: minimum, mm: millimetre, n: number of participants, SD: standard deviation, SEM: standard error of mean.

[†]Significant difference between age groups.
[‡]Significant difference between boys and girls.
[§]Significant difference between White and non-White participants.

Table 1. Measures of spread for spherical equivalent refraction, and ocular biometric parameters by age, gender and ethnicity, in the right eyes of study participants

The SER mean ± standard deviation in study participants (6–7 years 1.44 ± 1.25 D, 12–13 years 0.38 ± 1.61 D, p < 0.0001) were previously reported.¹⁴ The SER mean ± standard deviation for non-White participants (6–7 years 0.83 ± 1.00 D, 12–13 years –0.64 ± 1.98 D) were lower than White

participants (6–7 years 1.51 ± 1.26 D, 12–13 years 0.51 ± 1.51 D, p < 0.0001), with no gender differences (p = 0.09). The axial length mean ± standard deviation was shorter in 6–7-year-olds (22.53 ± 0.79 mm) than in 12–13-year-olds (23.50 ± 0.89 mm) (p < 0.0001) (Figure 1), longer in

boys (23.32 ± 0.95 mm) than girls (22.77 ± 0.92 mm) (p < 0.0001), and longer in non-White participants (23.21 ± 1.11) than White participants (23.05 ± 0.95 mm) (p = 0.006). The corneal radius mean ± standard deviation was lower in 6–7-year-olds (7.81 ±

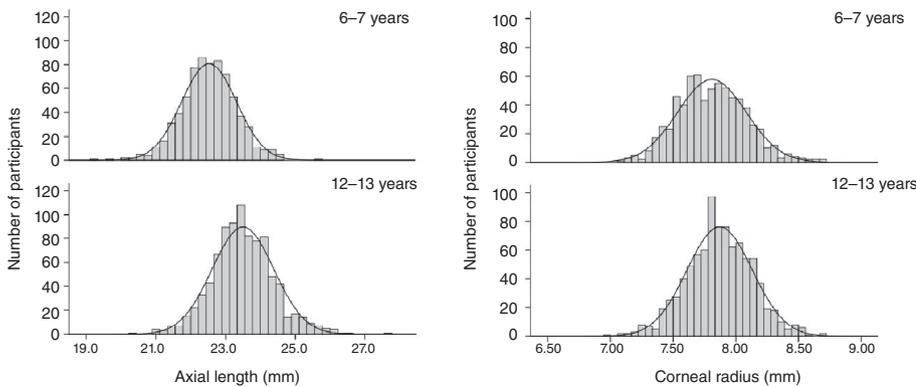


Figure 1. Distribution of axial length in 6-7-year-olds (top left image) and 12-13-year-olds (bottom left image). Distribution of mean corneal radius in 6-7-year-olds (top right image) and 12-13-year-olds (bottom right image).

0.27 mm) than 12-13-year-olds (7.87 ± 0.26 mm) ($p < 0.0001$) (Figure 1), lower for girls (7.75 ± 0.25 mm) than boys (7.92 ± 0.26 mm) ($p < 0.0001$), with no ethnic differences ($p = 0.06$).

The anterior chamber depth mean \pm standard deviation was shallower in 6-7-year-olds (3.40 ± 0.21 mm) than 12-13-year-olds (3.61 ± 0.11 mm) ($p < 0.0001$), shallower in girls (3.55 ± 0.25 mm) than in boys

(3.62 ± 0.26 mm) ($p < 0.0001$), with no ethnic differences ($p = 0.13$).

The axial length/corneal radius ratio mean \pm standard deviation was lower in 6-7-year-olds (2.89 ± 0.09) than 12-13-year-olds (2.99 ± 0.11) ($p < 0.0001$), lower for White participants (2.94 ± 0.11) than non-White participants (2.98 ± 0.12) ($p < 0.0001$), with no gender differences ($p = 0.30$).

Relationships between SER and ocular biometric parameters

The relationships between SER and ocular biometric parameters were examined using linear regression analysis (Table 2).

AXIAL LENGTH

An inverse relationship was found between axial length and SER ($r = -0.64$, $R^2 = 0.41$, $p < 0.0001$). The linear regression equation was represented by:

$$\text{Axial length} = 23.41 (\text{SER}) \quad [1]$$

The per-unit change in axial length had less impact on SER in 6-7-year-old non-White participants compared to White participants (6-7 years White: β co-efficient = -0.77 D, non-White: β co-efficient = -0.33 D, $p < 0.0001$). The reverse was found in the 12-13-year-olds, whereby the per-unit change in axial length had less impact on SER in White participants compared to non-White participants (12-13-year-old Whites: β co-efficient = -1.12 D, non-White β co-efficient = -1.36 D, $p < 0.0001$). For example, in White 6-7-year-olds axial length explained 23 per cent of the variability in SER ($R^2 = 0.23$); this

	Pearson correlation	β co-efficient (95% CI) [†]	Model R ²	F statistic	p-value
6-7 years (White)					
Axial length (mm)	-0.48	-0.77 (-0.88 to -0.66)	0.23	187.71	< 0.0001
Corneal radius (mm)	0.09	0.42 (0.06 to 0.77)	0.007	5.26	0.02
Axial length/corneal radius	-0.65	-9.34 (-10.10 to -8.48)	0.42	454.01	< 0.0001
Anterior chamber depth	-0.26	-1.16 (-2.34 to -0.08)	0.05	4.61	0.04
12-13 years (White)					
Axial length (mm)	-0.64	-1.12 (-1.22 to -1.03)	0.41	549.36	< 0.0001
Corneal radius (mm)	0.14	0.80 (0.39 to 1.20)	0.02	15.07	< 0.0001
Axial length/corneal radius	-0.82	-11.99 (-12.58 to -11.40)	0.67	1,575.33	< 0.0001
Anterior chamber depth	-0.34	-1.90 (-2.32 to -1.47)	0.12	77.86	< 0.0001
6-7 years (non-White)					
Axial length (mm)	-0.27	-0.33 (-0.60 to -0.06)	0.06	6.1	0.02
Corneal radius (mm)	-0.01	-0.05 (-0.97 to 0.87)	-0.01	0.01	0.91
Axial length/corneal radius	-0.47	-6.78 (-9.72 to -3.85)	0.21	21.19	< 0.0001
Anterior chamber depth	-0.07	-0.70 (-5.11 to 3.71)	0.01	0.11	0.74
12-13 years (non-White)					
Axial length (mm)	-0.72	-1.36 (-1.62 to -1.11)	0.52	111.03	< 0.0001
Corneal radius (mm)	0.08	0.54 (-0.89 to 1.98)	0.01	0.57	0.45
Axial length/corneal radius	-0.86	-13.70 (-15.33 to -12.07)	0.73	277.98	< 0.0001
Anterior chamber depth	-0.32	-2.62 (-4.33 to -0.92)	0.10	9.36	0.003

[†]In the regression model, spherical equivalent refractive error was the dependant variable, with each biometric variable as an explanatory variable. mm: millimetres.

Table 2. Association of ocular biometric parameters and spherical equivalent refraction in the right eyes of 6-7-year-old and 12-13-year-old study participants

dropped to six per cent in non-White 6–7-year-olds ($R^2 = 0.06$). In contrast, axial length explained 41 per cent of the variability in SER ($R^2 = 0.41$) in White 12–13-year-olds, which increased to 52 per cent in non-White 12–13-year-olds ($R^2 = 0.52$).

CORNEAL RADIUS

There was a significant, albeit weak, relationship between corneal radius and SER ($r = 0.07$, $R^2 = 0.005$, $p = 0.005$). Overall, corneal radius explained only 0.5 per cent of the variation in SER. The linear regression equation was represented by:

$$\text{Corneal radius} = 7.83 + 0.01 (\text{SER}) \quad [2]$$

Corneal radius was not correlated with SER in non-White participants in either age group (Table 2).

ANTERIOR CHAMBER DEPTH

Anterior chamber depth was negatively correlated with SER and overall, explained 11 per cent of the variability in SER ($r = -0.33$, $R^2 = 0.11$, $p < 0.0001$). The linear regression equation was:

$$\text{Anterior chamber depth} = 3.61 - 0.06 (\text{SER}) \quad [3]$$

AXIAL LENGTH/CORNEAL RADIUS RATIO

The axial length/corneal radius ratio was strongly correlated with SER ($r = -0.79$, $R^2 = 0.63$, $p < 0.001$). The linear regression equation was:

$$\text{Axial length/corneal radius ratio} = 2.99 - 0.06 (\text{SER}) \quad [4]$$

The relationship between the axial length/corneal radius ratio varied with ethnicity. Among White 6–7-year-olds, the axial length/corneal radius ratio explained variance in SER to a greater extent than among non-White participants (White 42 per cent versus non-White 21 per cent); however, among the older-age cohort the reverse was found (White 67 per cent versus non-White 73 per cent).

A linear regression model was calculated to examine the relationship between SER (dependent variable) with covariates axial length, corneal radius and anterior chamber depth jointly, while controlling for age and ethnicity. The covariates could significantly predict the SER ($r = 0.84$ and $R^2 = 0.73$, $F_{5,1,602} = 625.9$, $p < 0.001$); 73 per cent of the variance in SER was explained by

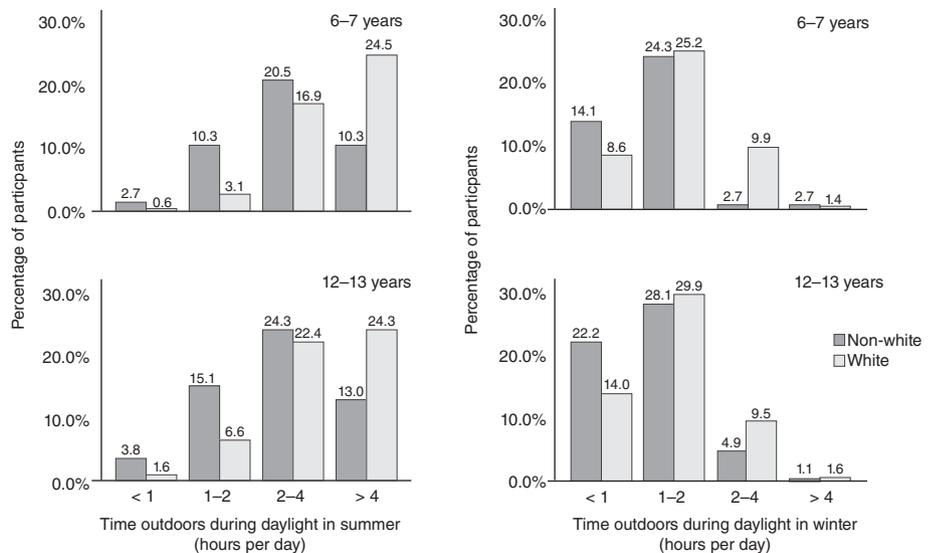


Figure 2. The percentage of participants in each category of time spent outdoors in summer (left images) and winter (right images), by age group (6–7-years top images, 12–13 years bottom images) and ethnicity (White participants light grey bars, non-White participants dark grey bars)

Average daily time spent outdoors during daylight	β	Standard error	95% CI	t	p-value
Spherical equivalent refraction (D)					
< 1 hour	-1.04	0.23	-1.48 to -0.60	-4.60	< 0.0001
1–2 hours	-0.41	0.12	-0.64 to -0.17	-3.36	0.001
2–4 hours	-0.11	0.08	-0.26 to 0.05	-1.38	0.167
> 4 hours	0 [†]				
Axial length (mm)					
< 1 hour	0.31	0.13	0.06 to 0.57	2.29	0.012
1–2 hours	0.17	0.07	0.03 to 0.31	2.40	0.016
2–4 hours	0.12	0.05	0.03 to 0.21	2.62	0.009
> 4 hours	0 [†]				
Axial length / corneal radius ratio					
< 1 hour	0.05	0.02	0.02 to 0.08	3.37	< 0.0001
1–2 hours	0.02	0.01	0.01 to 0.03	2.12	0.01
2–4 hours	0.01	0.01	-0.01 to 0.02	1.83	0.068
> 4 hours	0 [†]				

β : beta co-efficient, D: dioptre, mm: millimetre.
 p-values < 0.05 are shown in bold.
[†]This parameter is set to zero because it is redundant.

Table 3. Relationship between spherical equivalent refraction, axial length, axial length/corneal radius ratio and time spent outdoors during daylight in summer categories, controlling for age and ethnicity in all analysis

variance in axial length, corneal radius and anterior chamber depth. The linear regression equation was represented by:

$$\text{SER} = 6.32 - 1.91 (\text{axial length}) + 4.27 (\text{corneal radius}) + 1.45 (\text{anterior chamber depth}) \quad [5]$$

Time spent outdoors during daylight in summer and winter

Participants reported spending more time outdoors during daylight in summer than in winter ($p < 0.001$). Participants aged 6–7 years spent more time outdoors during daylight than 12–13-year-olds in summer ($p < 0.001$) and winter ($p = 0.01$). White participants spent more time outdoors during daylight than non-White participants in summer (6–7 years $p < 0.001$; 12–13 years $p < 0.001$), and winter (6–7 years $p = 0.002$; 12–13 years $p = 0.001$). Time spent outdoors was not associated with gender during winter ($p = 0.11$) or summer ($p = 0.053$). Figure 2 displays the percentage of participants in each time outdoors category by age and ethnicity.

Relationship between SER, ocular biometry and time outdoors

As time spent outdoors was significantly associated with both age group and ethnicity, in order to further investigate the relationship between time spent outdoors with SER and ocular biometric parameters, general linear models were constructed, controlling for both age and ethnicity in all analyses (Table 3).

SER

Participants in the least time outdoors group (< 1 hour per day) were more myopic by -1.04 D (CI -1.48 D to -0.60 D, $p < 0.0001$), and participants in the 1–2 hours outdoors group were more myopic by -0.41 D (CI -0.64 D to -0.17 D, $p = 0.001$) when compared to participants in the most time outdoors category (> 4 hours per day). There was no significant difference in SER between participants in the 2–4 hours outdoors category and > 4 hours outdoors category ($p = 0.17$).

AXIAL LENGTH

Axial length was 0.31 mm (CI 0.06 mm to 0.57 mm, $p = 0.01$) longer in the least time outdoors cohort; 0.17 mm (CI 0.03 mm to 0.31 mm, $p = 0.02$) longer in the 1–2 hours outdoors category; and 0.12 mm (CI 0.03 mm to 0.21 mm, $p = 0.01$) longer in the 2–4 hours outdoors per day category, when compared to participants in the most time outdoors category (> 4 hours per day).

AXIAL LENGTH/CORNEAL RADIUS RATIO

The axial length/corneal radius ratio was 0.05 (CI 0.02 to 0.08 , $p < 0.0001$) higher in the least time outdoors category (< 1 hour

per day), and 0.02 (CI 0.01 to 0.03 , $p = 0.01$) higher in the 1–2 hours outdoors per day category when compared to participants in the most time outdoors category (> 4 hours). There was no significant difference in the axial length/corneal radius ratio between participants in the 2–4 hours outdoors category and those in the most time outdoors ($p = 0.07$).

Neither corneal radius ($p = 0.34$) nor anterior chamber depth ($p = 0.10$) were associated with time outdoors during daylight in summer.

While increased time spent outdoors was significantly associated with a less myopic SER among 12–13-year-old White participants ($p < 0.0001$), when analysed separately, time outdoors was not associated with SER among non-White participants in

either age cohort (6–7 years $p = 0.42$, 12–13 years $p = 0.52$). Figure 3 displays boxplots which illustrate the distribution of SER in the various time spent outdoors categories in 6–7-year-old and 12–13-year-old White and non-White participants. The mean SER increased with increasing time outdoors in the White 12–13-year-old group.

Similarly, increased time outdoors was associated with shorter axial length in White participants ($p < 0.0001$), but not in non-White participants ($p = 0.35$). Figure 4 displays boxplots which illustrate the distribution of axial length data in each time outdoors category by age and ethnicity categories.

The means for SER and ocular biometric parameters are presented by age (6–7 years and 12–13 years), ethnicity (White, non-

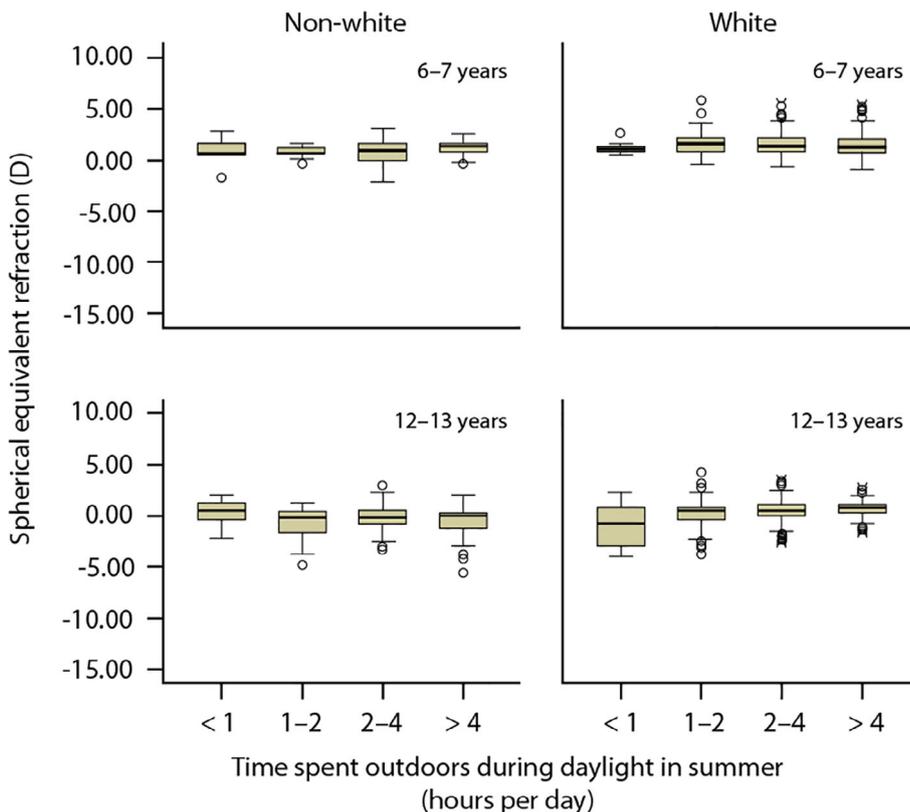


Figure 3. Boxplots showing the distribution of spherical equivalent refraction (diopetre) in time spent outdoors during daylight in summer categories in 6–7-year-olds (non-White participants top left image and White participants top right image), and 12–13-year-olds (non-White participants bottom left image and White participants bottom right image). In White 12–13-year-olds mean spherical equivalent refraction (SER) was significantly less myopic with increased time outdoors category (bottom right image). From top to bottom the five horizontal bars represent maximum, 75th percentile, median, 25th percentile; the whiskers mark the range of the data with the outliers (< 5th percentile or > 95th percentile) shown as grey dots.

White) and time outdoors during daylight in summer categories in Table 4.

Time spent outdoors during daylight in wintertime was not associated with SER ($p = 0.49$), axial length ($p = 0.64$), corneal radius ($p = 0.33$), axial length/corneal radius ratio ($p = 0.71$), or anterior chamber depth ($p = 0.56$).

Discussion

This is the first population-based study to analyse the association between SER and ocular biometrics, and associations between these parameters with time spent outdoors during daylight in schoolchildren in Ireland. Similar to many previously published studies when compared to White participants, the mean SER was significantly more myopic in non-White participants in both age cohorts and negatively associated with axial

length, with a longer axial length associated with more negative SER.^{1,2,26} For example, the longer axial length found in non-White participants in this study, mirrors the Aston Eye Study and the Child Heart and Health Study in England, where South Asian participants had longer axial length and a more myopic SER than White participants.^{1,26}

The extent to which axial length explained the variability in SER in this study increased with age (6–7 years 21 per cent, 12–13 years 43 per cent), which concurs with the NICER study (6–7 years 30 per cent, 12–13 years 47 per cent),² and contrasts with the Sydney Myopia Study (6–7 years 20 per cent, 12–13 years 10 per cent), which reported a lower prevalence of both hyperopia and myopia.²

In agreement with previous studies, the relationship between corneal radius and SER in the present study was weak.^{2,5} However, the significantly longer corneal radius

found in the older-age cohort compared to the younger-age cohort in this study contrasts with both the NICER study and the Sydney Myopia Study where no difference with age was found.²

Anterior chamber depth in 6–7-year-olds (3.40 mm) in the present study was shallower than reported in 6–7-year-old Australian children, where significantly shallower anterior chamber readings were found pre-cycloplegia (3.36 mm) when compared to post-cycloplegia (3.54 mm).²⁷ As anterior chamber depth was not measured prior to cycloplegia in this study, findings are likely to overestimate anterior chamber depth in the natural state. Further analysis of anterior chamber depth in the Irish population merits investigation due to the association between shallow anterior chambers with angle closure glaucoma.²⁸ Longer anterior chamber depth was associated with a more myopic SER in this study; this could be due to longer eyes having deeper anterior chambers although the resultant refractive effect of a longer anterior chamber is toward a less myopic SER.²⁷

The relationship between the axial length/corneal radius ratio and SER was linear and negatively associated with SER in the current study. Moreover, the axial length/corneal radius ratio best explained the variance in SER and this relationship strengthened with age. In contrast, a higher mean axial length/corneal radius ratio (over 3.00), was reported in Singaporean 7–9-year-olds and associated with a more negative SER,⁵ which more closely aligns with that found in non-White participants in the present study (6–7 years 2.99, 12–13 years 3.03).

The lowest mean axial length/corneal radius ratio in the present study was found among 6–7-year-old White participants (2.88) and associated with the highest mean SER (1.51 D). In comparison, the highest axial length/corneal radius ratio was found in non-White 12–13-year-olds (3.03) where the lowest SER was found (–0.61 D). While the axial length/corneal radius ratio has received considerable attention with regard to myopia progression in non-White communities,²⁹ its association with hyperopia found in Ireland is important and concurs with a previous study involving Saudi Arabian children aged 5–16 years, where the relationship persisted even in hyperopic amblyopic eyes.³⁰ For instance, the axial length/corneal radius ratio provides valuable information regarding refractive status

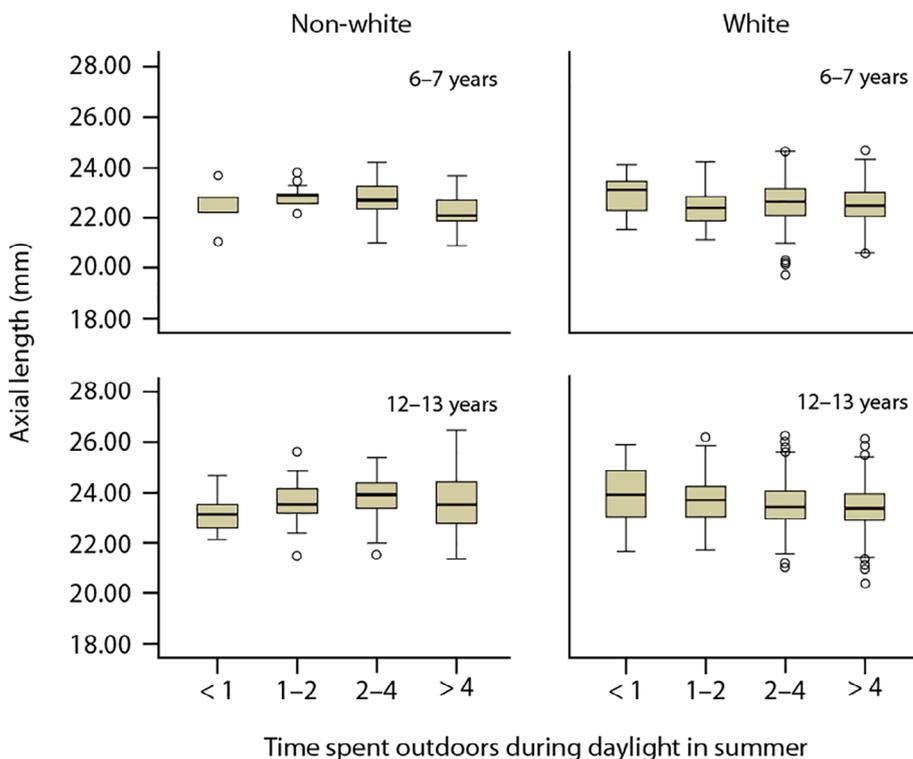


Figure 4. Boxplots of axial length (mm) in time spent outdoors during daylight in summer categories (x-axis) and axial length (y-axis) in 6–7-year-olds (non-White participants top left image and White participants top right image) and 12–13-year-olds (non-White bottom left image and White participants bottom right image). White participants aged 12–13 years had significantly shorter mean axial lengths with increasing time outdoors (bottom right image). The line in the grey box marks the median, the lower and upper edges of the box mark the lower and upper quartiles and the whiskers mark the range of the data with the outliers (< 5th percentile or > 95th percentile) shown as grey dots.

Mean (SE)	< 1 hour	1-2 hours	2-4 hours	> 4 hours	p-value	< 1 hour	1-2 hours	2-4 hours	> 4 hours	p-value
White 6-7 years						Non-White 6-7 years				
	n = 9	n = 44	n = 240	n = 347	-	n = 5	n = 19	n = 38	n = 19	-
SER	1.21 (0.21)	1.62 (0.20)	1.53 (0.09)	1.53 (0.06)	0.86	0.70 (0.74)	0.71 (0.14)	0.74 (0.18)	1.16 (0.19)	0.44
AL/CR	2.88 (0.02)	2.86 (0.01)	2.88 (0.01)	2.89 (0.01)	0.36	2.93 (0.04)	2.90 (0.02)	2.92 (0.01)	2.90 (0.04)	0.45
AL	22.65 (0.28)	22.41 (0.10)	22.60 (0.06)	22.47 (0.04)	0.17	22.34 (0.42)	22.58 (0.26)	22.78 (0.12)	22.23 (0.17)	0.12
CR	7.86 (0.08)	7.84 (0.05)	7.84 (0.02)	7.79 (0.01)	0.14	7.62 (0.14)	7.86 (0.04)	7.79 (0.04)	7.67 (0.07)	0.09
ACD	3.28 (0.03)	3.22 (0.20)	3.45 (0.05)	3.35 (0.03)	0.08	3.48 (0.08)	3.44 (0.05)	3.43 (0.05)	3.38 (0.03)	0.80
White 12-13 years						Non-White 12-13 years				
	n = 22	n = 94	n = 317	n = 345	-	n = 7	n = 28	n = 45	n = 24	-
SER	-1.14 (0.45)	0.05 (0.17)	0.52 (0.05)	0.72 (0.07)	< 0.0001	0.29 (0.56)	-0.95 (0.38)	-0.57 (0.31)	-0.70 (0.39)	0.52
AL/CR	3.09 (0.52)	3.01 (0.01)	2.99 (0.01)	2.97 (0.01)	< 0.0001	2.93 (0.02)	3.03 (0.02)	3.03 (0.02)	3.04 (0.02)	0.19
AL	24.00 (0.25)	23.70 (0.10)	23.45 (0.05)	23.40 (0.04)	< 0.0001	23.16 (0.32)	23.67 (0.17)	23.87 (0.16)	23.57 (0.25)	0.35
CR	7.77 (0.07)	7.87 (0.03)	7.86 (0.01)	7.89 (0.01)	0.12	7.90 (0.06)	7.83 (0.06)	7.88 (0.01)	7.89 (0.01)	0.22
ACD	3.70 (0.05)	3.68 (0.03)	3.63 (0.02)	3.60 (0.02)	0.08	3.38 (0.13)	3.57 (0.05)	3.57 (0.04)	3.60 (0.06)	0.35

ACD: anterior chamber depth, AL/CR: axial length/corneal radius ratio, AL: axial length, CR: corneal radius, n: number of participants, SE: standard error of mean, SER: spherical equivalent refraction.

Significant associations between time outdoors during daylight and spherical equivalent refraction and biometry are highlighted in bold (one-way analysis of variance, Bonferroni post hoc tests were run for axial length and SER and the AL/CR for the 12-13-year-old White participants which revealed SER increased, axial length shortened and the AL/CR decreased significantly with each outdoors category; however, there was no significant difference between 2-4 hours and > 4 hours outdoors during daylight for SER [p = 0.50] and AL [p > 0.99] and AL/CR [p = 0.06]), p-values < 0.05 are shown in bold.

Table 4. Relationship between spherical equivalent, ocular biometric parameters and time spent outdoors during daylight in summer time in the right eyes of study participants

(myopia, hyperopia progression), particularly in situations where cycloplegic agents are not appropriate.²⁹

Effect of time spent outdoors during daylight

Ireland is situated between 51 to 55 degrees of north latitude, and day length varies from a minimum of 7.5 hours in winter to a maximum of 17 hours during summer.¹³ In Ireland, school holidays last between two to three months in summer (June, July and August), two weeks in winter (the last week in December and first week in January) and two weeks in spring to coincide with Easter (March, April). The relationship between SER, ocular biometric parameters and time spent outdoors during daylight in winter was not significant, which aligns with previous studies where daylight hours were limited during winter.^{8,31}

Conversely the relationship between time outdoors and SER during summer was strong, with increased time outdoors associated with a less myopic SER, and shorter axial length, in agreement with earlier studies.^{8,10} In the present study spending less than two hours outdoors per day in summer resulted in significantly more myopic

SER and higher axial length/corneal radius ratio when compared to participants in the 'more than four hours outdoors per day' cohort. In contrast to the Danish study where time outdoors was associated with increased corneal power,⁸ the present study did not find a relationship between corneal curvature and time outdoors in summer.

The current study did not find an association between time outdoors and SER and time outdoors and axial length in non-White participants. Notably, non-White participants in the current study reported spending significantly less time outdoors, during both winter and summer, than White participants. Likewise, a recent study reported children in Singapore were on average exposed to five hours less light exposure per week than children living in Brisbane, despite 12-hour days in both locations.³²

While the relationship between light exposure and ocular growth is not fully understood, it has been suggested that sunlight/bright light could trigger retinal dopamine release which slows axial elongation.³³ Circadian rhythms have been demonstrated in ocular structures with corresponding diurnal variation in ocular

biometric measurements.³⁴ Hence, ocular diurnal rhythms may be involved in ocular growth regulation.³⁵

Daylight is a natural 'zeitgeber' (or time cue) for synchronising the internal circadian rhythm, due to temporal fluctuations in daylight intensity and spectral distribution;³⁶ however, artificial lighting disrupts circadian rhythms (circadian entrainment),³⁶ which may affect ocular growth.²¹ For example, studies involving chickens and monkeys established that altering the dark/light cycle resulted in significant changes in ocular growth with exposure to bright light during the day providing a protective effect against experimentally induced form-deprivation myopia.^{37,38} Moreover, light levels indoors, even in rooms with windows, are lower indoors than outdoors,³⁹ with an association between the use of light-emitting diode lamps and longer axial lengths reported.⁴⁰ Hence, there may be a minimum level of ambient illumination appropriate to school class rooms to prevent myopia development or progression. For example, one school-based intervention study increased ambient luminance to > 300 lux on desks and > 500 lux on blackboards, and found that axial elongation was slowed with a less myopic

shift in SER in the intervention group when compared to a control group.⁴¹

As to what degree the protective effect of daylight exposure against a more myopic SER is due to being outdoors, during daylight, or simply not being indoors and engaged in near vision activities, is as yet not fully understood.²⁰ Thus, the results in this study support earlier studies that time spent outdoors during daylight is an important modifiable factor.^{3,4,17} Also similar to previous studies, the present study found non-White participants may be engaged in a more indoor-centric lifestyle.^{32,42} Due to the limited number of non-White participants in this study, further multi-ethnic studies involving larger populations born and living in a northern European setting are crucial due to the limited day length in winter, and changeable weather systems which affect light intensity. In addition, precise quantification of light exposure would be facilitated by the use of wearable devices to objectively measure not only time spent outdoors but also light intensity exposure which would be more revealing than the questionnaire-based data involving daylight categories used in the present study.^{32,43}

Conclusion

The distribution of ocular biometric parameters in schoolchildren in Ireland mirrors many other studies involving mainly White children. The axial length/corneal radius ratio was highly correlated with SER, and this correlation strengthened with age. Ethnic differences in SER corresponded with ethnic differences in ocular biometry. Of particular interest, compared to White participants, non-White participants had longer axial length, corresponding with a more myopic SER. Also, non-White participants spent significantly less time outdoors during daylight than White participants.

While study findings are not longitudinal, the age-specific data provide some insights into refractive error patterns and how they change with age. The correlates of these biometric variables and their interactions were variable and multifaceted, and their relationship with SER appeared to strengthen with increasing age. However, longitudinal studies in Ireland examining the association between ocular biometry, SER, and time spent outdoors in daylight across seasons are required to confirm study findings.

School intervention programs promoting time outdoors during winter of not less than two hours per day, when daylight hours are limited and coincide with school hours, ought to be considered in Ireland.

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