CrossMark

AMERICAN ACADEMY OF OPHTHALMOLOGY
The Eye M.D. Association

Increasing Prevalence of Myopia in Europe and the Impact of Education

Katie M. Williams, MPhil, FRCOphth,[1,2] Geir Bertelsen, MD, PhD,[3,4] Phillippa Cumberland, MSc, BA,[5] Christian Wolfram, MD,[6] Virginie J.M. Verhoeven, MD, MSc,[7,8] Eleftherios Anastasopoulos, MD,[9] Gabriëlle H.S. Buitendijk, MD, MSc,[7,8] Audrey Cougnard-Grégoire, PhD,[10,11] Catherine Creuzot-Garcher, MD, PhD,[12] Maja Gran Erke, MD, PhD,[13] Ruth Hogg, PhD,[14] René Höhn, MD,[6] Pirro Hysi, MD, PhD,[2] Anthony P. Khawaja, MPhil, FRCOphth,[15] Jean-François Korobelnik, MD,[10,11] Janina Ried, PhD,[16] Johannes R. Vingerling, MD, PhD,[7,8] Alain Bron, MD,[12] Jean-François Dartigues, MD, PhD,[10,11] Astrid Fletcher, PhD,[17] Albert Hofman, MD, PhD,[8] Robert W.A.M. Kuijpers, MD, PhD,[7,8] Robert N. Luben, MSc,[15] Konrad Oxele, MD,[18] Fotis Topouzis, MD, PhD,[9] Therese von Hanno, MD, PhD,[4,19] Alireza Mirshahi, MD,[6] Paul J. Foster, PhD, FRCOphth,[20] Cornelia M. van Duijn, PhD,[8] Norbert Pfeiffer, MD,[6] Cécile Delcourt, PhD,[10,11] Caroline C.W. Klaver, MD, PhD,[7,8] Jugnoo Rahi, PhD, FRCOphth,[5,20] Christopher J. Hammond, MD, FRCOphth,[1,2] on behalf of the European Eye Epidemiology (E^3) Consortium

Purpose: To investigate whether myopia is becoming more common across Europe and explore whether increasing education levels, an important environmental risk factor for myopia, might explain any temporal trend.

Design: Meta-analysis of population-based, cross-sectional studies from the European Eye Epidemiology (E^3) Consortium.

Participants: The E^3 Consortium is a collaborative network of epidemiological studies of common eye diseases in adults across Europe. Refractive data were available for 61 946 participants from 15 population-based studies performed between 1990 and 2013; participants had a range of median ages from 44 to 78 years.

Methods: Noncycloplegic refraction, year of birth, and highest educational level achieved were obtained for all participants. Myopia was defined as a mean spherical equivalent ≤ -0.75 diopters. A random-effects meta-analysis of age-specific myopia prevalence was performed, with sequential analyses stratified by year of birth and highest level of educational attainment.

Main Outcome Measures: Variation in age-specific myopia prevalence for differing years of birth and educational level.

Results: There was a significant cohort effect for increasing myopia prevalence across more recent birth decades; age-standardized myopia prevalence increased from 17.8% (95% confidence interval [CI], 17.6–18.1) to 23.5% (95% CI, 23.2–23.7) in those born between 1910 and 1939 compared with 1940 and 1979 ($P = 0.03$). Education was significantly associated with myopia; for those completing primary, secondary, and higher education, the age-standardized prevalences were 25.4% (CI, 25.0–25.8), 29.1% (CI, 28.8–29.5), and 36.6% (CI, 36.1–37.2), respectively. Although more recent birth cohorts were more educated, this did not fully explain the cohort effect. Compared with the reference risk of participants born in the 1920s with only primary education, higher education or being born in the 1960s doubled the myopia prevalence ratio–2.43 (CI, 1.26–4.17) and 2.62 (CI, 1.31–5.00), respectively—whereas individuals born in the 1960s and completing higher education had approximately 4 times the reference risk: a prevalence ratio of 3.76 (CI, 2.21–6.57).

Conclusions: Myopia is becoming more common in Europe; although education levels have increased and are associated with myopia, higher education seems to be an additive rather than explanatory factor. Increasing levels of myopia carry significant clinical and economic implications, with more people at risk of the sight-threatening complications associated with high myopia. *Ophthalmology 2015;122:1489-1497 © 2015 by the American Academy of Ophthalmology. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).*

Supplemental material is available at www.aaojournal.org.

Myopia (near-sightedness) occurs when a distant object's image is formed anterior to the retinal plane, most commonly as a result of an increased axial length. This results in blurred distant vision and, unlike hyperopia, requires refractive correction at all ages and severity for clear focus. Myopia is already the most common eye condition worldwide, but the prevalence is significantly increasing, especially in Southeast Asia.[1–3] In Europe, Australia, and the United States, the

© 2015 by the American Academy of Ophthalmology
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/). Published by Elsevier Inc.

http://dx.doi.org/10.1016/j.ophtha.2015.03.018
ISSN 0161-6420/15

prevalence of myopia seems to be lower[4,5]; however, there is evidence of an increasing prevalence in the United States and elsewhere,[6–8] particularly among young adults.[9] This is of concern because myopia, even when appropriately corrected, is associated with an increased risk of sight-threatening diseases, such as myopic maculopathy, retinal detachment, glaucoma, and cataract.[10] Myopic maculopathy is currently untreatable and already contributes to visual impairment in working-age adults.[11] Increasing myopia levels in Europe carry implications for public health policy in both the provision of clinical services and the economic sequelae from the resulting visual impairment among the working population.

Myopia is a highly heritable trait,[12,13] and to date a number of genetic polymorphisms have been associated with refractive error, albeit explaining only a small proportion of this heritability.[14,15] Environmental factors play a key role in myopia development and must explain the recent changes in prevalence.[16] Myopia has been associated with education, near work, urbanization, prenatal factors, socioeconomic status, cognitive ability, season of birth, light, and time spent outdoors.[2,16–25] One of the strongest and most replicated risk factors is educational attainment,[16,26] and there is some evidence of interaction between genetic factors and education influencing the risk of myopia.[27] The increased levels of higher education over the 20th century[28] might be a causative factor, or marker of a causative factor, for increasing myopia prevalence.

The aims of this study are to identify whether myopia is becoming more common across Europe and to examine whether increasing levels of education explain any temporal trend, using data from more than 60 000 participants from the European Eye Epidemiology (E^3) Consortium.

Methods

Study Population

The E^3 consortium is a collaborative initiative to share and meta-analyze epidemiologic data on common eye diseases across Europe. Thirty-three studies are currently part of the consortium, and a range of ophthalmic data are available on approximately 124 000 individuals from population-based and case-control cohorts. All studies adhere to the tenets of the Declaration of Helsinki, and relevant local ethical committee approvals with specific study consent were obtained.

Refractive error measurements from 68 350 adults within the 15 E^3 population-based studies that had data on refractive error were included. These included population-based cross-sectional or cohort studies, with 2 studies recruiting participants nationally and 13 studies recruiting from a local population. Further details on each study are provided in Table 1 and the Supplementary information (available at www.aaojournal.org). Exclusion criteria included subjects who had cataract or refractive surgery, retinal detachment, or other conditions, such as keratoconus, which might influence refraction (n = 6404). Data on age at refraction and birth year were available for 61 946 individuals, with information on education level for 60 125 subjects. Participants were mainly middle to late age; 98% were of European descent (where ethnicity was known), predominantly from Northern and Western Europe; and refractive examinations were performed from 1990 to 2013 (Table 1).

Study Variables

Noncycloplegic refractions were performed on all individuals using subjective refraction, autorefraction, or a combination of focimetry with subjective refraction. Spherical equivalent was calculated using the standard formula (spherical equivalent = sphere + [cylinder/2]). Myopia was defined as ≤ -0.75 diopters. Myopia prevalence by age was calculated, using 5- and 10-year age bands from $\geq$15 years to $\geq$90 years. To study the impact of education on myopia, given the variation in educational systems across Europe, we established a simplified 3-tier level of education across all cohorts. Primary education was defined as those leaving school before 16 years of age, secondary education was defined as those leaving education up to the age of 19 years, and higher education was defined as those leaving education at or after the age of 20 years. Those aged younger than 20 years at the time of refraction (and therefore unable to have reached the highest education tier) were excluded from this analysis to avoid misclassification bias.

We investigated the evidence for a cohort effect on increasing myopia prevalence by observing variations in myopia prevalence within defined age bands. These analyses are focused on the age range constituting the majority of our cohort (40–80 years of age, birth year 1910–1979, n = 56 088), meaning the youngest and oldest participants, for whom we had no comparative birth cohort, were not considered. Prevalence between different birth cohorts was examined, initially using decade bins (1910–1970) and subsequently in 2 birth cohort groups divided by the median birth decade (1940–1949). Finally we examined the influence of education by examining the myopia prevalence between birth cohorts with the additional stratification of educational status.

Statistical Analysis

Study-specific summary data for myopia prevalence were obtained and combined in a random-effect meta-analysis stratified by age. A random-effects model was chosen over a fixed-effects model to allow for expected heterogeneity between studies as a result of varying study design. Age was standardized with demographic distribution adjustments to age-specific estimates according to the European Standard Population 2010.[29] Evidence for the presence of a cohort effect was investigated using random-effect meta-analyses of myopia prevalence stratified by age and birth year, and subsequently age, birth year, and educational level. Differences between estimates of myopia prevalence were evaluated using the analysis of variance test, proportion z tests, and prevalence ratios (relative difference in prevalence against a defined baseline). Differences were considered significant at $P < 0.05$.

Statistical analysis was performed using Stata statistical software version 13.1 (StataCorp LP, College Station, TX). Graphical outputs[30] were obtained using Stata, Origin version 9.0 (OriginLab Corp, Northampton, MA), or ggplot2(30) in R software (R Foundation for Statistical Computing, Vienna, Austria; available at http://www.R-project.org).

Results

In this meta-analysis of 61 946 adults, the overall myopia prevalence was 24.3% (95% confidence interval [CI], 20.1–28.5), with an age-standardized prevalence in Europe of 30.6% (95% CI, 30.3–30.8). Age-stratified analyses[31] revealed a high prevalence in young adults (47.2% [95% CI, 41.8–52.5] in those aged 25–29 years), which was almost double the prevalence in those of middle to older age (27.5% [95% CI, 23.5–31.5] in those aged 55–59 years). There were no significant differences in the myopia prevalence by gender.[31]

Table 1. Description of the 15 European Eye Epidemiology Consortium Studies Included in this Meta-Analysis of Refractive Error

Study	Data Collection Period	Study Design	Total Participants with Refraction	Refraction Method	Exclusions* (Cataract Surgery)	Total Participants Included	Median Age, yrs (Range)	Gender, % Female	Ethnicity, % European (% Unknown)	Higher Education, %	Crude Myopia Prevalence, %
Northern Europe											
1958 British Birth Cohort, UK	2002–2003	Population-based birth cohort (N)	2502	Autorefraction	7 (0)	2495	44 (44–46)	51.7	98.0 (9.2)	29.9	48.7
EPIC-Norfolk, UK	2004–2011	Population-based cross-sectional study (L)	8508	Autorefraction	1110 (971)	7444	67 (48–92)	54.5	99.7 (0)	17.9	23.0
Tromsø Eye Study, Norway	2007–2008	Population-based cohort (L)	6565	Autorefraction	773 (700)	5792	61 (38–87)	55.9	NA (100)	32.5	19.4
TwinsUK, UK	1998–2010	National twin cohort (N)	6245	Autorefraction	161 (61)	6095	55 (16–85)	91.2	98.2 (23.9)	22.3	31.4
Southern Europe											
Thessaloniki Eye Study, Greece	1999–2005	Cross-sectional population-based study (L)	2259	Subjective	316 (303)	1952	69 (60–94)	44.7	100 (0)	Unknown	14.2
Western Europe											
ALIENOR, France	2006–2008	Population-based cohort (L)	951	Autorefraction	333 (318)	618	79 (73–93)	56.6	NA (100)	20.0	16.7
ERF, Netherlands	2002–2005	Family-based cross-sectional study (L)	2708	Subjective	46 (45)	2662	49 (14–87)	55.1	100 (0)	16.9	21.2
Gutenberg Health Study, Germany	2007–2012	Population-based cohort (L)	14 679	Autorefraction	610 (610)	14 069	54 (35–74)	49.4	NA (100)	37.6	31.9
KORA, Germany	2004–2005	Population-based cohort (L)	3078	Autorefraction	706 (177)	2372	55 (35–84)	50.4	100 (0)	14.7	36.1
Montrachet, France	2009–2013	Population-based cohort (L)	1143	Autorefraction	584 (562)	576	81 (76–92)	57.5	NA (100)	Unknown	19.1
Rotterdam Study I, Netherlands	1990–1993	Population-based cohort (L)	6748	Subjective	182 (172)	6566	68 (55–106)	59.3	98.5 (2.0)	11.6	16.4
Rotterdam Study II, Netherlands	2000–2002	Population-based cohort (L)	2689	Subjective	110 (110)	2579	62 (55–99)	54.8	87.8 (0.1)	22.3	21.9
Rotterdam Study III, Netherlands	2005–2008	Population-based cohort (L)	3624	Subjective	94 (74)	3530	56 (46–97)	56.3	NA (100)	31.4	32.5
POLA, France	1995–1997	Population-based cohort (L)	2464	Autorefraction	157 (128)	2315	70 (60–93)	55.8	NA (100)	7.3	16.2
Mixed											
EUREYE: Norway, UK, France, Italy, Greece, and Estonia	2000–2002	Population-based cross-sectional survey in 7 cities (L)	4187	Autorefraction or focimetry with subjective refraction	1305 (517)	2882	72 (65–95)	56.7	NA (100)	30.0	15.6
Total cohort	1990–2013		68 350		6404 (4748)	61 946	62	57.6	98.1	36.0	25.8

ALIENOR = Antioxydants, Lipides Essentiels, Nutrition et maladies OculaiRes Study; EPIC = European Prospective Investigation into Cancer; ERF = Erasmus Rucphen Family Study; EUREYE = European Eye Study; KORA = Kooperative Gesundheitsforschung in der Region Augsburg; L = local; N = national; NA = not available; POLA = Pathologies Oculaires Liées à l'Age Study. Myopia classified in those with refraction ≤ -0.75 diopters.
*Exclusions = cataract surgery, refractive surgery, retinal detachment or other conditions affecting refraction.

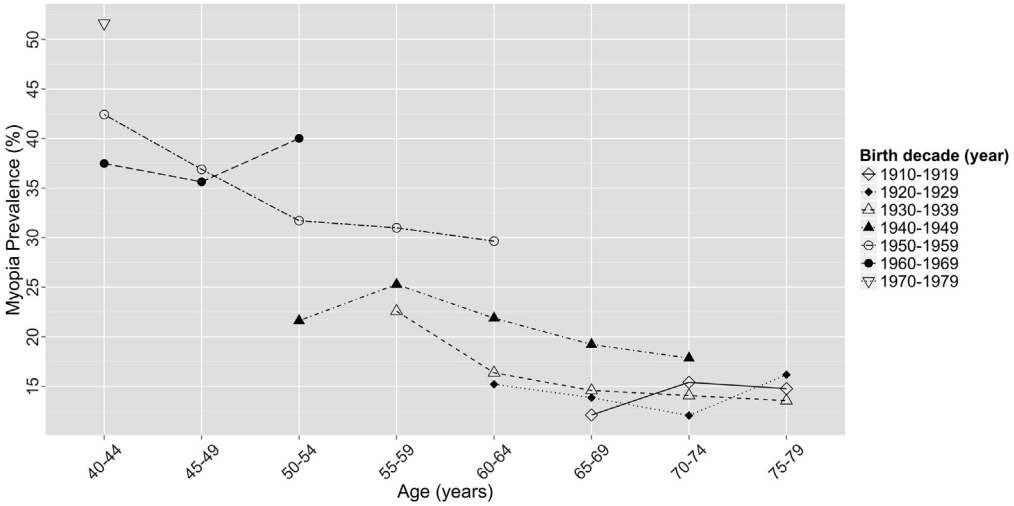


Figure 1. Prevalence of myopia (spherical equivalent ≤−0.75 diopters) against age stratified by decade of birth. Individuals aged 40 to 79 years included.

Cohort Effect for Increasing Myopia Prevalence

There was a trend of higher myopia prevalence with more recent birth decade across all age groups (Fig 1), although sample sizes for some point estimates were low, resulting in wide CIs (Table 2, available at www.aaojournal.org).

We examined the prevalence of myopia in 2 birth cohort groups (divided by the median birth decade): those born between 1910 and 1939 (n = 22 660) and those born between 1940 and 1989 (n = 33 428) (Fig 2). Myopia prevalence in a variance model was significantly higher in the more recent birth cohort group (P = 0.03). Age-standardized myopia prevalence over a comparable age range of 50 to 79 years increased from 17.8% (95% CI, 17.6−18.1) in those born in 1910−1939 to 23.5% (95% CI, 23.2−23.7) in those born in 1940−1979. In age-specific analyses, the prevalence of myopia in those aged 50 to 59 years (at the time of their refraction) was 22.5% (95% CI, 20.2−24.9) in those born before 1940, compared with 29.2% (95% CI, 25.3−33.0) in those born after 1940 (P = 0.004). A similar significant increase of 15.3% (95% CI, 13.4−17.3) to 21.2% (95% CI, 18.6−23.8) was observed in those aged 60 to 69 years (P < 0.001).

Influence of Education on Myopia Risk and the Cohort Effect

The association between education and myopia was investigated in the 13 studies from which these data were available (n = 60 125 participants). Educational level was significantly associated with myopia prevalence across all age strata (P < 0.0001). Overall, the age-standardized myopia prevalence for those completing primary, secondary, and higher education was 25.4% (95% CI, 25.0−25.8), 29.1% (95% CI, 28.8−29.5), and 36.6% (95% CI, 36.1−37.2), respectively. In those aged 35 to 84 years, the majority of study subjects, myopia prevalence in participants with higher education was approximately double those with primary education (Fig 3). For example, in subjects aged 45 to 49 years when tested, the myopia prevalence was 26.3% (95% CI, 20.1−32.5) compared

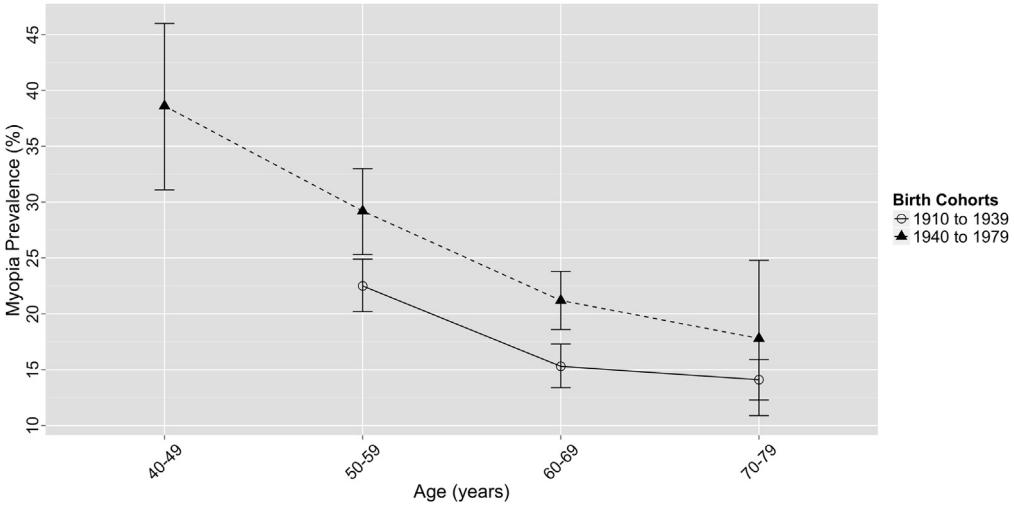


Figure 2. Prevalence of myopia (spherical equivalent ≤−0.75 diopters) as a function of age for 2 birth cohorts (1910−1939, 1940−1979) with 95% confidence intervals.

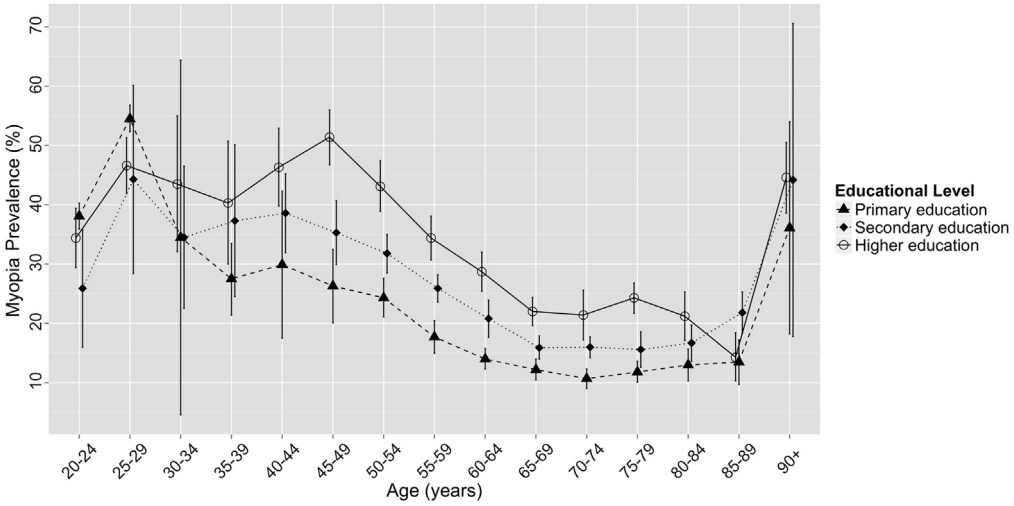


Figure 3. Prevalence of myopia (spherical equivalent ≤−0.75 diopters) with 95% confidence interval stratified by highest educational level achieved: primary education, leaving education at age <16 years; secondary education, leaving school at age ≤19 years; higher education, leaving school at age ≥20 years.

with 51.4% (95% CI, 46.7−56.0) for those with primary and higher education, respectively, and in those aged 60 to 64 years, myopia prevalence was 14.0% (95% CI, 12.3−15.8) compared with 28.7% (95% CI, 25.4−32.0) for those with primary and higher education, respectively. The trends observed are less clear in younger subjects (<35 years) in Figure 3, most likely because of small sample sizes (n = 216 aged 20−25 years, n = 336 aged 25−30 years), which are further stratified by education level with corresponding wide CIs.

Levels of education throughout Europe have increased in the past 90 years (Fig 4). The proportion of individuals progressing to higher education increased from 4% of those born in the 1900s to 16% in the 1920s, 20% in the 1940s, 33% in the 1960s, and approximately 61% in the 1980s.

However, although those born more recently were more likely to have achieved a higher educational level, this alone did not explain the cohort effect of increasing myopia. As shown in Figure 5, for individuals aged 45 to 65 years (age range selected for minimal age-related myopia variance and large available sample size), the increase in myopia prevalence with a more recent birth decade was observed across all educational groups. This was most pronounced for participants achieving only a primary education, in whom myopia prevalence increased from 10.7% (95% CI, 7.6−13.8) to 28.1% (95% CI, 18.1−38.0) between birth decades 1920 to 1929 and 1960 to 1969 ($P = 0.001$). The corresponding increase in myopia in those with higher education was from 26.0% (95% CI, 17.4−34.6) to 40.2% (95% CI, 30.5−50.0) ($P = 0.03$). Compared with the reference risk of participants with primary education and born in the 1920s, the myopia prevalence ratio for those achieving a higher education was 2.43 (95% CI, 1.26−4.17) and for those born in the 1960s was 2.62 (95% CI, 1.31−5.00). Individuals born in the 1960s and completing higher education had approximately 4 times the baseline risk, with a prevalence ratio of 3.76 (95% CI, 2.21−6.57). Thus, the individual associations of educational level and birth cohort had an additive effect on myopia prevalence.

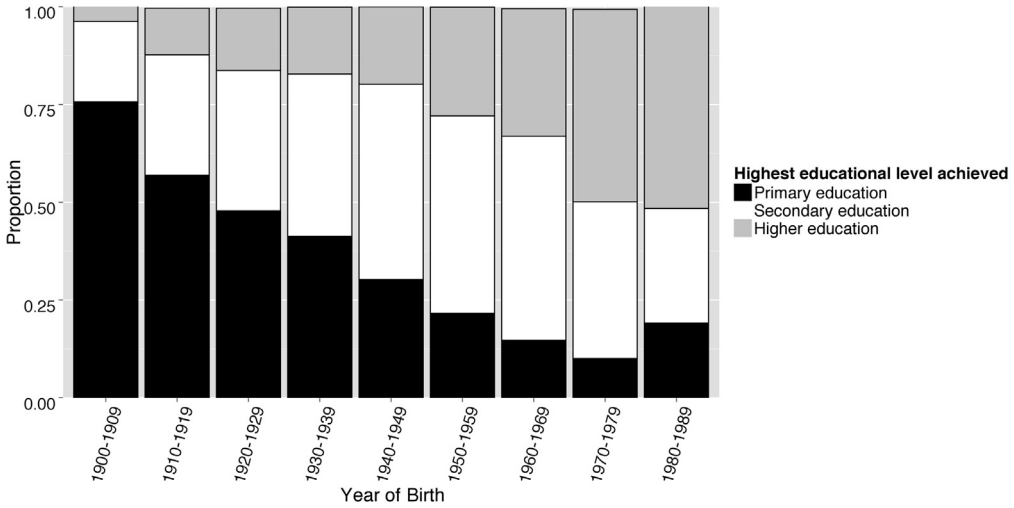


Figure 4. Distribution of highest educational level achieved, stratified by year of birth (1900−1989): primary education, leaving education at age <16 years; secondary education, leaving school at age ≤19 years; higher education, leaving school at age ≥20 years.

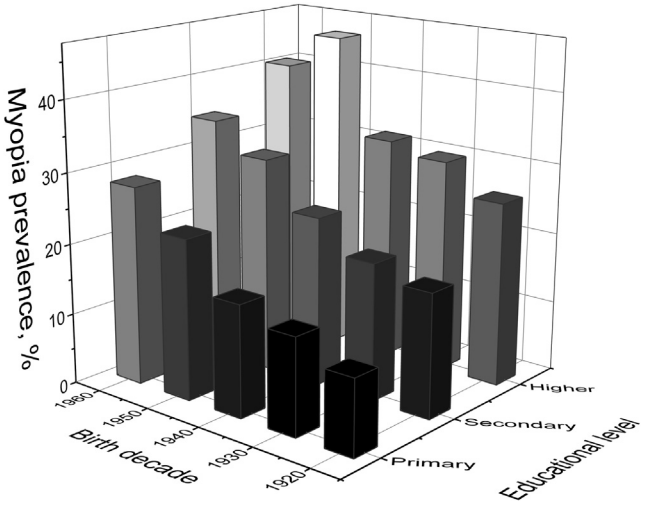


Figure 5. Myopia prevalence (spherical equivalent ≤ -0.75 diopters) by birth cohort and educational level in individuals aged 45 to 65 years: primary education, leaving education at age <16 years; secondary education, leaving school at age ≤19 years; higher education, leaving school at age ≥20 years.

Discussion

Our study provides the first evidence that myopia is becoming more common across Western and Northern Europe, with a clear trend of higher myopia prevalence in participants with a more recent birth year (Fig 1). This is similar to the increase reported in North America and, albeit to a lesser extent, Southeast Asian populations.[6,7,32,33] Evidence of increasing myopia prevalence carries clinical and economic implications. The increased requirement for detection and treatment of myopia, entailing glasses, contact lenses, or more recently laser refractive surgery, has significant implications for clinical optometric and ophthalmic service provision, and the health care system. Additional ophthalmic services will be needed for treatable sight-threatening complications, such as retinal detachment, glaucoma, and cataract.[10,34] The increasing prevalence of myopia also implies that untreatable complications, such as myopic maculopathy, most commonly seen in high myopia, will become more common. This will result in more visual impairment in middle- to older-aged individuals, including a proportion of the working-age population, with consequent economic implications.

Myopia has been strongly associated with education,[2,21,24,35] and we explored this using a simple 3-tier classification of educational level. Increasing educational level had a strong effect, with myopia twice as common in those achieving a higher education compared with participants leaving school before 16 years of age. There was a clear trend of increasing prevalence of myopia across the tiers of education level, suggesting a potential additive effect of years of education. This interesting association may reflect a number of factors: greater near work activities with more education and less time in outdoor light, shared genetic factors underlying myopia and intelligence, or factors related to educational opportunity, such as socioeconomic status or maternal nutrition. These associations have been explored in younger cohorts,[18–21,36,37] although causal pathways are yet to be fully understood.

Reasons for the observed cohort effect are clearly multifactorial, and education is an obvious possible explanation; in our data, only 12% of participants born in the 1920s went on to higher education, compared with 33% born in the 1960s. This educational expansion has been observed across Europe in both men and women, with a sharp trajectory toward mass higher education after World War II.[28,38] In addition to the disruption of education and economic consequences of World War II, adverse health outcomes have been reported in young people growing up at that time, notably diabetes, depression, and heart disease.[39] Although there is no known direct link between these health issues and myopia, the deprivation may have affected eye growth and resulting refraction. Certainly there was an increase in myopia in subjects born after 1950, but it is difficult to be certain what aspect of the seismic changes in Europe after the war might be responsible.

Although the younger generations were more educated, we found a clear increase in the prevalence of myopia across the birth cohorts within each educational stratum, as well as the additive effect of educational status. Therefore, increasing levels of myopia were not explained by education alone, and a more recent birth year and higher educational level had an additive effect on myopia risk. Our simple 3-tier education stratification may be subject to residual confounding from variation in educational practices, and it may be these, rather than changes in education level, that are contributing to the observed cohort effect. In the latter half of the last century, there was increasing use of computers, increasing length of the educational day with increased after-school tuition, and less outdoor play as a result of reduced recess time.[35]

Study Limitations

The E^3 consortium has provided a large data set to meta-analyses' temporal trends and educational associations for myopia prevalence across Europe. Limitations to this consortium meta-analysis include heterogeneity between studies. Contributing studies inherently differed in study design and cohort sampling. In acknowledgment of this heterogeneity, we performed a random-effect rather than a fixed-effect meta-analysis, assuming no fixed effect between studies. There are also differences between European countries in terms of urbanization, economy, social class, education, and lifestyle, which are known to influence myopia. Data on these variables at an individual or study-specific level were not uniformly available, and data often were collected from middle-aged and older participants, so retrospective collection of potential contributing factors such as outdoor exposure, amount of reading, and area of residence during the critical first 20 years of refractive error development would be impossible. In addition, potential multicollinearity of these likely highly correlated factors (e.g., reading and education) would make assessment of separate effects difficult. In an attempt to reduce heterogeneity arising from these associated

factors, we stratified the random-effects meta-analysis by age and educational level (both significantly associated with myopia). Applicability of our findings is greatest for middle- to older-aged individuals and for those from Northern and Western European countries, given the sampled ages and the location of the E^3 studies (Table 1), although ultimately the degree to which these studies are representative of the underlying population is unknown.

Further limitations include the crude nature in which education was classed, which as previously acknowledged may result in residual confounding. In addition, education status was collected retrospectively and therefore prone to recall error, possibly heightened in older participants. Refractions were all noncycloplegic, although this is reasonable given the age of participants.[40,41] Finally, these data are not longitudinal, so we have not examined reasons for the lower prevalence with age within birth decades, although the cohort effect we identified may be part of this explanation. Other reasons include the well-known hyperopic shift with age and could include other factors, such as censoring with age if myopic subjects receive earlier cataract surgery.

In conclusion, the prevalence of myopia is increasing in Europe, a finding that is not fully explained by increasing education levels despite higher educational achievement being associated with myopia and becoming more widespread in Europe. The changes in prevalence are similar to those observed in North America, although they remain far less than those identified in Southeast Asia, possibly because of differing intensity of education from an early age.[1,6,35] High levels of myopia were detected in the younger adults with a more recent birth year, of whom approximately half were affected. This has significant implications for the future; increasing myopia prevalence, and specifically high levels in younger individuals, will potentially result in an increasing burden of associated visual impairment in the future.

Acknowledgments. The authors thank all the participants and teams involved in the contributing cohorts.

1958 British Birth Cohort. The 1958 British Birth Cohort biomedical survey was funded by the Medical Research Council (grant G0000934, Health of the Public initiative, principal grant holders C. Power and D. Strachan).

Montachet. Regional Council of Burgundy, PHRC Interregional.

ALIENOR. The Alienor study received financial support from Laboratoires Théa (Clermont-Ferrand, France). Laboratoires Théa participated in the design of the study, but no sponsor participated in the collection, management, statistical analysis, and interpretation of the data, nor in the preparation, review or approval of the present manuscript.

EPIC-Norfolk. EPIC-Norfolk infrastructure and core functions are supported by grants from the Medical Research Council (G1000143) and Cancer Research UK (C864/A14136). The clinic for the third health examination was funded by Research into Ageing (262). Mr Khawaja is a Wellcome Trust funded Clinical Research Fellow. Mr Foster has received additional support from the Richard Desmond Charitable Trust (via Fight for Sight) and the Department for Health through the award made by the National Institute for Health Research to Moorfields Eye Hospital and the UCL Institute of Ophthalmology for a specialist Biomedical Research Centre for Ophthalmology. None of the funding organizations had a role in the design or conduct of the research.

EUREYE. The EUREYE Study was supported by grant QLK6-CT-1999-02094 from the European Commission Vth Framework. Additional funding for cameras was provided by the Macular Disease Society. The Alicante site was supported by grants FIS 01/1692Eand RCESPC03/09 from the Spanish Ministry of Health; by Centro de Investigacion Biomédica en Red de Epidemiologiá y Salud Pública; and by grants CTGCA/2002/06 and G03/136 from the Generalitat Valenciana.

Gutenberg Health Study. The Gutenberg Health Study is funded by the government of Rhineland-Palatine ("Stiftung Rheinland-Pfalz für Innovation," contract number AZ 961-386261/733), the research programs "Wissen schafft Zukunft" and "Schwerpunkt Vaskuläre Prävention" of the University Medical Center Mainz, Germany, and its contract with Boehringer Ingelheim, Germany, and PHILIPS Medical Systems including an unrestricted grant for the Gutenberg Health Study. The sponsors and funding organizations played no role in the design or conduct of this research.

KORA. The KORA research platform (KORA, Cooperative Research in the Region of Augsburg) was initiated and financed by the Helmholtz Zentrum München—German Research Center for Environmental Health, which is funded by the German Federal Ministry of Education and Research and by the State of Bavaria. The KORA-Age project was financed by the German Federal Ministry of Education and Research (BMBF FKZ 01ET0713) as part of the "Health in old age" program. The funders had no role in study design, data collection, and analysis, decision to publish, or preparation of the manuscript.

POLA. This study was supported by the Institut National de la Santé et de la Recherche Médicale (Inserm), Paris, France; by grants from the Fondation de France, Department of Epidemiology of Ageing, Paris, the Fondation pour la Recherche Médicale, Paris, the Région Languedoc-Roussillon, Montpellier, France, and the Association Retina-France, Toulouse; and by financial support from Rhônes Poulenc, Essilor, Specia, and Horiba ABX Montpellier, and the Centre de Recherche et d'Information Nutritionnelle, Paris. The sponsors and funding organizations played no role in the design or conduct of this research.

Rotterdam Study and ***ERF Study*** were supported by the Netherlands Organization of Scientific Research (NWO) (Vidi 91796357 to C.C.W. Klaver), NWO Investments (175.010.2005.011, 911-03-012 to the Rotterdam Study), the Netherlands Genomics Initiative (NGI)/NWO (050-060-810 to the Rotterdam Study), Erasmus Medical Center and Erasmus University, Rotterdam, The Netherlands, Netherlands Organization for Health Research and Development (ZonMw), UitZicht, Stichting Combined Ophthalmic Research Rotterdam (CORR), the Research Institute for Diseases in the Elderly (014-93-015, RIDE2), the Ministry of Education, Culture and Science, the Ministry for Health, Welfare and Sports, the European Commission (DG XII), the Municipality of Rotterdam, the Netherlands Genomics Initiative/NWO, Center for Medical Systems Biology of NGI, Lijf en Leven, MD, Fonds, Henkes Stichting, Stichting Nederlands Oogheelkundig Onderzoek, Swart van Essen, Bevordering van Volkskracht, Blindenhulp, Landelijke Stichting voor Blinden en Slechtzienden, Rotterdamse Vereniging voor Blindenbelangen, OOG, Algemene Nederlandse Vereniging ter Voorkoming van Blindheid, the Rotterdam Eye Hospital Research Foundation, Erasmus Trustfonds, and Topcon Europe.

Thessalonki Eye Study. The Thessaloniki Eye Study is supported in part by International Glaucoma Association, London,

UK; UCLA Center for Eye Epidemiology, Los Angeles, CA; Health Future Foundation, Creighton University, Omaha, NE; Texas Tech University Health Sciences Center, Lubbock, TX; Pfizer, Inc, New York, NY; Glaucoma Research Education Foundation, Indianapolis, IN; Pharmacia Hellas, Athens, Greece; Novartis Hellas, Athens, Greece. All the grants were unrestricted.

Tromsø Eye Study received funding from the Norwegian Extra Foundation for Health and Rehabilitation through EXTRA funds, the Research Council of Norway, the Northern Norway Regional Health Authority and the University of Tromsø.

TwinsUK received funding from the Wellcome Trust (grant no. 081878) and the National Institute for Health Research (NIHR) BioResource Clinical Research Facility and Biomedical Research Centre based at Guy's and St. Thomas' NHS Foundation Trust and King's College London. K.M.W. acknowledges financial support from a Medical Research Council Clinical Research Training Fellowship.

References

1. Morgan IG, Ohno-Matsui K, Saw S-M. Myopia. Lancet 2012;379:1739–48.
2. Pan CW, Ramamurthy D, Saw SM. Worldwide prevalence and risk factors for myopia. Ophthalmic Physiol Opt 2012;32:3–16.
3. Bourne RR, Stevens GA, White RA, et al. Causes of vision loss worldwide, 1990—2010: a systematic analysis. Lancet Glob Health 2013;1:e339–49.
4. Group TEDPR. The prevalence of refractive errors among adults in the United States, Western Europe, and Australia. Arch Ophthalmol 2004;122:495–505.
5. Vitale S, Ellwein L, Cotch MF, et al. Prevalence of refractive error in the United States, 1999-2004. Arch Ophthalmol 2008;126:1111–9.
6. Vitale S, Sperduto RD, Ferris FLI. Increased prevalence of myopia in the United States between 1971-1972 and 1999-2004. Arch Ophthalmol 2009;127:1632–9.
7. Lee KE, Klein BE, Klein R, Wong TY. Changes in refraction over 10 years in an adult population: the Beaver Dam Eye study. Invest Ophthalmol Vis Sci 2002;43:2566–71.
8. Parssinen O. The increased prevalence of myopia in Finland. Acta Ophthalmol 2012;90:497–502.
9. Bar Dayan Y, Levin A, Morad Y, et al. The changing prevalence of myopia in young adults: a 13-year series of population-based prevalence surveys. Invest Ophthalmol Vis Sci 2005;46:2760–5.
10. Flitcroft DI. The complex interactions of retinal, optical and environmental factors in myopia aetiology. Prog Retin Eye Res 2012;31:622–60.
11. Buch H, Vinding T, la Cour M, et al. Prevalence and causes of visual impairment and blindness among 9980 Scandinavian adults. Ophthalmology 2004;111:53–61.
12. Lopes MC, Andrew T, Carbonaro F, et al. Estimating heritability and shared environmental effects for refractive error in twin and family studies. Invest Ophthalmol Vis Sci 2009;50:126–31.
13. Hammond CJ, Snieder H, Gilbert CE, Spector TD. Genes and environment in refractive error: the twin eye study. Invest Ophthalmol Vis Sci 2001;42:1232–6.
14. Verhoeven VJ, Hysi PG, Wojciechowski R, et al. Genome-wide meta-analyses of multiancestry cohorts identify multiple new susceptibility loci for refractive error and myopia. Nat Genet 2013;45:314–8.
15. Kiefer AK, Tung JY, Do CB, et al. Genome-wide analysis points to roles for extracellular matrix remodeling, the visual cycle, and neuronal development in myopia. PLoS Genet 2013;9:e1003299.
16. Morgan I, Rose K. How genetic is school myopia? Prog Retin Eye Res 2005;24:1–38.
17. Young FA, Leary GA, Baldwin WR, et al. The transmission of refractive errors within Eskimo families. Am J Optom Arch Am Acad Optom 1969;46:676–85.
18. Williams C, Miller LL, Gazzard G, Saw SM. A comparison of measures of reading and intelligence as risk factors for the development of myopia in a UK cohort of children. Br J Ophthalmol 2008;92:1117–21.
19. Saw SM, Chua WH, Hong CY, et al. Nearwork in early-onset myopia. Invest Ophthalmol Vis Sci 2002;43:332–9.
20. Ip JM, Saw SM, Rose KA, et al. Role of near work in myopia: findings in a sample of Australian school children. Invest Ophthalmol Vis Sci 2008;49:2903–10.
21. Dirani M, Shekar SN, Baird PN. The role of educational attainment in refraction: the Genes in Myopia (GEM) twin study. Invest Ophthalmol Vis Sci 2008;49:534–8.
22. Sherwin JC, Reacher MH, Keogh RH, et al. The association between time spent outdoors and myopia in children and adolescents: a systematic review and meta-analysis. Ophthalmology 2012;119:2141–51.
23. Wu PC, Tsai CL, Wu HL, et al. Outdoor activity during class recess reduces myopia onset and progression in school children. Ophthalmology 2013;120:1080–5.
24. Rahi JS, Cumberland PM, Peckham CS. Myopia over the lifecourse: prevalence and early life influences in the 1958 British birth cohort. Ophthalmology 2011;118:797–804.
25. Durkin SR, Tan EW, Casson RJ, et al. Distance refractive error among Aboriginal people attending eye clinics in remote South Australia. Clin Experiment Ophthalmol 2007;35:621–6.
26. Mirshahi A, Ponto KA, Hoehn R, et al. Myopia and level of education: results from the Gutenberg Health Study. Ophthalmology 2014;121:2047–52.
27. Verhoeven VJ, Buitendijk GH, Consortium for Refractive Error and Myopia (CREAM), Rivadeneira F, Uitterlinden AG, et al. Education influences the role of genetics in myopia. Eur J Epidemiol 2013;28:973–80.
28. Schofer E, Meyer JW. The worldwide expansion of higher education in the twentieth century. Am Sociol Rev 2005;70:898–920.
29. Eurostat EC. Revision of the European Standard Population: Report of Eurostat's Task Force. Eurostat Methodologies and Working Papers. Luxembourg: Publications Office of the European Union; 2013.
30. Wickham H. ggplot2: Elegant Graphics for Data Analysis. New York: Springer; 2009.
31. Williams KM, Verhoeven VJ, Cumberland P, et al. Prevalence of refractive error in Europe: the European Eye Epidemiology (E3) Consortium. Eur J Epidemiology 2015;30:305–15.
32. Kim EC, Morgan IG, Kakizaki H, et al. Prevalence and risk factors for refractive errors: Korean National Health and Nutrition Examination Survey 2008-2011. PloS One 2013;8:e80361.
33. Koh V, Yang A, Saw SM, et al. Differences in prevalence of refractive errors in young Asian males in Singapore between 1996-1997 and 2009-2010. Ophthalmic Epidemiol 2014;21:247–55.
34. Kanthan GL, Mitchell P, Rochtchina E, et al. Myopia and the long-term incidence of cataract and cataract surgery: the Blue Mountains Eye Study. Clin Experiment Ophthalmol 2014;42:347–53.
35. Morgan IG, Rose KA. Myopia and international educational performance. Ophthalmic Physiol Opt 2013;33:329–38.

36. Borchert MS, Varma R, Cotter SA, et al. Risk factors for hyperopia and myopia in preschool children the multi-ethnic pediatric eye disease and Baltimore pediatric eye disease studies. Ophthalmology 2011;118:1966–73.
37. Saw SM, Tan SB, Fung D, et al. IQ and the association with myopia in children. Invest Ophthalmol Vis Sci 2004;45:2943–8.
38. Breen R, Luijkx R, Muller W, Pollak R. Long-term trends in educational inequality in Europe: class inequalities and gender differences(1). Eur Sociol Rev 2010;26:31–48.
39. Kesternich I, Siflinger B, Smith JP, Winter JK. The effects of World War II on economic and health outcomes across Europe. Rev Econ Stat 2014;96:103–18.
40. Krantz EM, Cruickshanks KJ, Klein BE, et al. Measuring refraction in adults in epidemiological studies. Arch Ophthalmol 2010;128:88–92.
41. Sanfilippo PG, Chu BS, Bigault O, et al. What is the appropriate age cut-off for cycloplegia in refraction? Acta Ophthalmol 2014;92:e458–62.

Footnotes and Financial Disclosures

Originally received: October 14, 2014.
Final revision: March 13, 2015.
Accepted: March 13, 2015.
Available online: May 13, 2015. Manuscript no. 2014-1631.

[1] Department of Ophthalmology, King's College London, St. Thomas' Hospital, London, United Kingdom.

[2] Department of Twin Research and Genetic Epidemiology, King's College London, St. Thomas' Hospital, London, United Kingdom.

[3] Department of Ophthalmology, University Hospital of North Norway, Tromsø, Norway.

[4] Department of Community Medicine, Faculty of Health Sciences, UiT The Arctic University of Norway, Tromsø, Norway.

[5] Life Course, Epidemiology and Biostatistics Section, UCL Institute of Child Health, London, United Kingdom.

[6] University Medical Center, Department of Ophthalmology, Mainz, Germany.

[7] Department of Ophthalmology, Erasmus Medical Center, Rotterdam, The Netherlands.

[8] Department of Epidemiology, Erasmus Medical Center, Rotterdam, The Netherlands.

[9] Department of Ophthalmology, Aristotle University of Thessaloniki, Thessaloniki, Greece.

[10] University Bordeaux, Bordeaux, France.

[11] ISPED, Centre INSERM U897-Epidemiologie-Biostatistique, Bordeaux, France.

[12] Department of Ophthalmology, Eye and Nutrition Research Group UMR 1324 INRA, University Hospital Dijon, France.

[13] Department of Ophthalmology, Oslo University Hospital, Oslo, Norway.

[14] Centre for Experimental Medicine, Institute of Clinical Science, Queen's University Belfast, Belfast, United Kingdom.

[15] Department of Public Health and Primary Care, Institute of Public Health, University of Cambridge School of Clinical Medicine, Cambridge, United Kingdom.

[16] Institute of Genetic Epidemiology, Helmholtz Center Munich, German Research Center for Environmental Health, Neuherberg, Germany.

[17] London School of Hygiene and Tropical Medicine, London, United Kingdom.

[18] Institute of Human Genetics, Klinikum rechts der Isar, Technische Universität, Munich, Germany.

[19] Department of Ophthalmology, Nordland Hospital, Norway, Bodø, Norway.

[20] NIHR Biomedical Research Centre, Moorfields Eye Hospital NHS Foundation Trust & UCL Institute of Ophthalmology, London, United Kingdom.

Presented in part at: the Association for Research in Vision and Ophthalmology Meeting, May 4−8, 2014, Orlando, Florida.

Financial Disclosure(s):
The author(s) have no proprietary or commercial interest in any materials discussed in this article.

The sponsor or funding organization has no role in the design or conduct of this research.

Author Contributions:

Conception and design: Williams, Cumberland, Rahi, Delcourt, Klaver, Hammond, Hogg, Hysi, Khawaja, Bron, Fletcher, Foster

Data collection: Williams, Verhoeven, Cumberland, Bertelsen, Wolfram, Anastasopoulos, Buitendijk, Cougnard-Grégoire, Creuzot-Garcher, Erke, Hogg, Höhn, Hysi, Khawaja, Korobelnik, Ried, Vingerling, Bron, Dartigues, Hofman, Kuijpers, Luben, Oxele, Topouzis, von Hanno, Mirshahi, van Duijn, Pfeiffer

Analysis and interpretation: Williams, Verhoeven, Cumberland, Bertelsen, Wolfram, Rahi, Delcourt, Klaver, Hammond, Anastasopoulos, Buitendijk, Cougnard-Grégoire, Creuzot-Garcher, Erke, Hogg, Höhn, Hysi, Khawaja, Korobelnik, Ried, Vingerling, Bron, Dartigues, Fletcher, Hofman, Kuijpers, Luben, Oxele, Topouzis, von Hanno, Mirshahi, Foster, van Duijn, Pfeiffer, Delcourt, Klaver, Rahi, Hammond

Obtained funding: none

Overall responsibility: Williams, Verhoeven, Cumberland, Bertelsen, Wolfram, Rahi, Delcourt, Klaver, Hammond, Anastasopoulos, Buitendijk, Cougnard-Grégoire, Creuzot-Garcher, Erke, Hogg, Höhn, Hysi, Khawaja, Korobelnik, Ried, Vingerling, Bron, Dartigues, Fletcher, Hofman, Kuijpers, Luben, Oxele, Topouzis, von Hanno, Mirshahi, Foster, van Duijn, Pfeiffer, Delcourt, Klaver, Rahi, Hammond

Abbreviations and Acronyms:
CI = confidence interval; **D** = diopters; **E^3** = European Eye Epidemiology.

Correspondence:
Christopher J. Hammond, MD, FRCOphth, Departments of Ophthalmology & Twin Research, King's College London, 3rd Floor, Block D, South Wing, St. Thomas' Hospital, Westminster Bridge Rd., London SE1 7EH, UK. E-mail: chris.hammond@kcl.ac.uk.