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Original Article – Clinical Science

Change in the prevalence of myopia in Australian middle-aged adults across 20 years

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ABSTRACT

Background: The prevalence of myopia is increasing globally including in Europe and parts of Asia but Australian data are lacking. This study aim described the change in myopia prevalence in middle-aged Australian adults over approximately a 20-year period.

Methods: Two contemporary Western Australian studies (conducted in mid-late 2010s): the coastal-regional Busselton Healthy Ageing Study (BHAS) and the urban Gen1 of the Raine Study (G1RS) were compared to two earlier studies (early-mid 1990s) in Australia: the urban Blue Mountains Eye Study (BMES) and urban/regional Melbourne Visual Impairment Project (MVIP). Refractive error was measured by autorefraction, vertometry, or subjective refraction. Participants (49–70 years) of European descent without self-reported/diagnosed cataract, corneal disease, or refractive or corneal surgery were included.

Results: After exclusions, data were available from 2,217, 1,760, 700, 2,987 and 756 participants from BMES, urban MVIP, regional MVIP, BHAS, and G1RS, respectively. The mean age ranged from 57.1±4.6 years in the G1RS to 60.1±6.0 years in the BMES; 44-48% of participants were male. When stratified by location, the contemporary urban G1RS cohort had a higher age-standardised myopia prevalence than the urban MVIP and BMES cohorts (29.2%, 16.4%, and 23.9%, $p<0.001$). The contemporary coastal-regional BHAS had a higher age-standardised myopia prevalence than the regional MVIP cohort (19.4% vs 13.8%, $p=0.001$).

Conclusions: We report an increase in myopia prevalence in older adults in Australia born after World War II compared to cohorts born before, accounting for urban/regional location. The prevalence of myopia remains relatively low in middle-aged Australian adults.

Key Words: Myopia, Adults, Australia, Epidemiology

1. INTRODUCTION

Myopia (near-sightedness) is a common condition caused by a mismatch between the refractive power of the cornea and lens and the axial length of the eye. Myopia is corrected by wearing glasses, contact lenses, or refractive surgery. However, these measures are costly for the individual and public health systems and higher levels of myopia also impose an increased risk of blinding diseases such as maculopathy, retinal detachment, glaucoma and cataract.[1]

It has been predicted that, by the year 2050, half the world's population will be myopic.[2] The myopia epidemic appears as momentous as other contemporary epidemics of chronic disease such as obesity[3] and diabetes. While the surge in myopia is clearly evident in East Asia[4] and to a lesser extent in Europe[5] and the USA[6], there is a paucity of data regarding whether a corresponding increase has also occurred in Australia. As the prevalence of refractive errors naturally varies with age, it is necessary to compare consecutive cross-sectional studies conducted on the same age groups to determine if the prevalence is increasing.[5]

Two landmark population-based studies investigating the prevalence of eye diseases in Australian adults were conducted in the early 1990s: the Blue Mountains Eye Study (BMES) and the Melbourne Visual Impairment Project (MVIP). We aimed to evaluate early evidence for a myopia epidemic in Australia by comparing the prevalence of myopia in the BMES and MVIP to two age-matched contemporary studies of Australian adults, the largely urban Generation 1 of the Raine Study (G1RS) and the coastal-regional Busselton Healthy Ageing Study (BHAS), both conducted in the 2010s.

2. METHODS

2.1 Blue Mountains Eye Study

The baseline BMES was conducted from 1992–1994. All non-institutionalised individuals aged 49 years and older and residing in two urban postcode areas west of Sydney, New South Wales, were eligible to participate. Of 4433 eligible residents, 3654 (82.4%) participated in the eye examination.[7]

All participants underwent non-cycloplegic autorefraction (Model 530; Humphrey, San Leandro, CA) and these data were used to assess refractive status. Cataract status was assessed from clinical photographs taken of the lens after dilation of the pupil during the eye examination.[8] Participants self-reported educational level and qualifications and any history of eye conditions or procedures.[9]

2.2 Melbourne Visual Impairment Project (urban and regional cohorts)

The MVIP ran from 1992–1994. All non-institutionalised individuals aged $\geq$40 years and residing in randomly selected Australian Bureau of Statistics Census Collector Districts in metropolitan Melbourne and regional Victoria were eligible.[10] A total of 5520 individual were identified as eligible to participate.[11] Of these, 4744 (86%) had an eye examination, including 3271 urban participants and 1473 regional participants.[12]

Refractive status was determined from non-cycloplegic subjective refraction, following an autorefraction (Humphrey 590 Automatic Refractor, Zeiss, Oberkochen, Germany) in participants for whom presenting visual acuity (VA) was worse than 0.04 logMAR ($6/6^{-2}$ Snellen) on a logMAR chart. In participants who had VA of 0.04 logMAR letters or better, refractive error was taken to be 0 (emmetropic) if not wearing glasses or, if they wore glasses, as the prescription of their current glasses measured using a Humphrey lens analyser (Zeiss, Oberkochen, Germany).[12] Unfortunately, we were not able to obtain the autorefractor results from the MVIP, the vertometry or subjective refraction outcomes were taken as the refractive error. Cataract status was assessed using slit-lamp examination during the examination and graded using the Wilmer scale.[13] Participants completed an interview during the eye examination to report education history as well as health and ocular history.

2.3 Busselton Healthy Ageing Study

The BHAS was conducted from 2010–2015 in Busselton, a regional town located on the coast 200 km south of Perth, Western Australia. All non-institutionalised residents of the Shire of Busselton aged between 49 and 64 years of age in 2010 were eligible to participate.[14] Of 6690 eligible adults, 5107 (76%) participated in the BHAS. Participants underwent a brief eye examination in the BHAS including autorefraction and autokeratometry (ARK-30, Nidek, Japan) after instillation of tropicamide 1% eye drops. Participants self-reported education and ophthalmic history, and cataract and refractive surgery status was determined from self-report. Calibrated autorefraction data was not available for participants who attended between 1/1/2013–31/7/2014 (n=1544, 30%) and these participants were excluded from this analysis.

2.4 Generation 1 of the Raine Study

The G1RS is part of the longitudinal, multigenerational Raine Study, which was initiated as a randomised controlled trial investigating the effects of repeated ultrasounds on neonatal outcomes. Between 1989–1992, 2900 pregnant women between 16-20 weeks' gestation were enrolled in the Raine Study; with their spouses, these women form the Gen1 cohort of the Raine Study.[15] From 2015–2017, participants were invited to participate in the Gen1 26-year follow-up. A total of 1098 (19%) individuals participated: 636 (22%) mothers and 462 (16%) fathers. All participants underwent non-cycloplegic autorefraction (ARK-1, Nidek, Japan). Participants self-reported their demographics and ocular and medical history, including specific questions on previous cataract diagnosis, cataract surgery, laser refractive surgery, and other eye procedures.

2.5 UK Biobank

For international comparison to a predominantly European cohort, we compared the prevalence of myopia and high myopia in the four Australian Studies to the UK Biobank (n=80,220).[16] The UK Biobank comprises a large community-based cohort of 40- to 69-year-old adults. Recruitment and health/medical examinations were conducted in 2006–2010 but an eye component was only added to the examinations at the final one-quarter of the study (late 2009 to 2010). Refractive status was assessed by non-cycloplegic autorefraction and participants were excluded if they self-reported a history of cataract.

2.6 Statistical Analysis

As the BHAS only included 49- to 70-year-old participants and all studies comprised a majority of European participants, to ensure the studies were age-matched and ethnicity-matched, only participants aged 49–70 years inclusive (Figure 1) and who were of European descent (as determined using self-administered questionnaire) from all studies were included in the analysis. At the time of the recent studies, this age group also happened to be the "baby boomer" generation. Participants were additionally excluded if: they did not have refractive error data; self-reported or were diagnosed during the examination with cataract or a corneal disease. Participants with a history of refractive, corneal or cataract surgery, procedures known to impact refractive error, were further excluded.

Figure 1: Age range of participants from all four studies, with red lines indicating the age range included in the current study. BHAS= Busselton Healthy Aging Study; G1RS= Gen1 of the Raine Study; BMES= Blue Mountains Eye Study; MVIP= Melbourne Visual Impairment Project. Years in brackets refers to year of eye examination.

Spherical equivalent was calculated as spherical refractive error + ½ cylindrical refractive error. Myopia and high myopia were defined as mean spherical equivalent of both eyes ≤-0.50 dioptres (D) and ≤-5.00D, respectively. Due to changes in the level of qualifications over time (e.g. many courses that were once diplomas are now bachelor degrees), self-reported educational attainment or qualification were categorised into a binary post-secondary school qualification (yes/no) variable. Prevalence and 95% confidence intervals [CI] of myopia and high myopia are reported. The age-standardised prevalence of myopia and high myopia for the contemporary and earlier cohorts were calculated using 2011 and 1991 Australian census data as the reference population(https://www.abs.gov.au/census), respectively, while the age-standarised rates for the UK cohort was calculated using the 2009 UK census data (https://www.ons.gov.uk/census). Independent t test/ANOVA or linear regression was used to compare continuous variables between studies and comparison of proportions/chi-square test or logistic regression was used to compare categorical/dichotomous outcomes between studies. Where difference between studies were statistically significant, post-hoc pairwise comparisons were made to identify which two (or more) studies differed between each other.

3. RESULTS

From the five Australian cohorts, data were available for 14,603 participants. Of these, 8420 (57.7%) participants were included in the analysis: 2217 (61%) from BMES, 1760 (53.8%) from urban MVIP, 700 (47.5%) from regional MVIP, 2987 (58%) from BHAS and 756 (69%) from G1RS. Participants included in the MVIP urban and regional analysis had fewer post-school qualifications than those excluded from the analysis (Urban: 26% included vs 52% excluded [$p < 0.001$]; regional: 30% vs 37% [$p = 0.032$]). Participants included in the BMES, on the other hand, had more post-school qualifications than those excluded (80% vs 26%; $p < 0.001$). The BMES participants included also comprised more males than those excluded (45% vs 41%; $p = 0.021$). There were no other differences in sex or post-school qualification between those included in or excluded from the analysis. The participant and refractive error characteristics from the Australian studies are shown in Table 1.

Table 1: Characteristics of the four cohorts of Australian adults after application of age, ethnicity and ocular history exclusion criteria

	Urban cohorts				Regional cohorts		
	BMES (n=2217)	Urban MVIP (n=1760)	G1RS (n=756)	p-value	Regional MVIP (n=700)	BHAS (n=2987)	p-value
Year of birth	1922–1942	1922–1945	1944–1968		1922–1945	1946–1964	
Age (years), mean (SD)	60.5 (6.0)	58.7 (6.0)	57.1 (4.6)	<0.001[a]	58.4 (6.6)	58.2 (5.4)	0.40
Male, n (%)	988 (44.5%)	842 (47.8%)	334 (44.2%)	0.08	339 (48.4%)	1376 (46.1%)	0.26
Post-school qualification, n (%)	1299 (58.6%)	462 (26.3%)	559 (77.1%)	<0.001[a]	211 (30.1%)	1426 (49.2%)	<0.001
Spherical equivalent (D), mean (SD)	0.37 (2.04)	0.38 (1.70)	-0.14 (2.0)	<0.001[b]	0.34 (1.47) [b]	0.24 (1.53)	0.12
Myopia, n (%)	472 (21.3%)	286 (16.3%)	226 (29.9%)	<0.001[a]	97 (13.9)[c]	586 (19.6%)	<0.001
High myopia, n (%)	5 (2.4%)	92 (5.2%)	30 (4.0%)	<0.001[a]	5 (0.7%)[c]	39 (1.3%)[c]	0.19

BMES: Blue Mountains Eye Study; MVIP: Melbourne Visual Impairment Project; BHAS: Busselton Healthy Ageing Study; G1RS: Generation 1 Raine Study

Cohort difference analysed using chi-square test for categorical variables and independent t-test (regional MVIP vs BHAS) or one-way analysis of variance (BMES vs urban MVIP vs G1RS) as appropriate

[a] Statistically different between all 3 cohorts (BMES, urban MVIP, and G1RS)

[b] G1RS cohort significantly different from the BMES and urban MVIP cohorts

Figure 2 shows the prevalence of myopia and high myopia for each age category in each of the five cohorts as well as the UK Biobank. Compared to the UK Biobank, the prevalence of myopia was lower in the BHAS, BMES, and MVIP cohorts (all p<0.001), but there was no significant difference in the prevalence of myopia between the UK Biobank and G1RS cohort (p=0.45; Figure 2). The prevalence of high myopia was significantly higher in the UK Biobank compared to the G1RS (p=0.01), BHAS (p<0.001), BMES (p<0.001), and MVIP (p<0.001) cohorts (Figure 2).

Figure 2: Prevalence of myopia (-0.50 D or worse) and high myopia (-5.00 D or worse). The age-standardised prevalence rates are additionally shown in the graph legends

3.1 Evidence for change in myopia prevalence

Crude myopia and high myopia prevalence are shown in Table 1. To account for differences in the distribution of ages between the four studies (Figure 1), we compared the age-standardised prevalence rates of myopia and high myopia. The age-standardised prevalence of myopia and high myopia was highest in the more recent G1RS cohort (29.2% [95%CI: 26.0-32.4]; 3.9% [95%CI: 2.5-5.3], respectively), followed by the BMES cohort (23.9% [95%CI: 22.1-25.7; 2.7% [95%CI: 2.0-3.4]), the BHAS cohort (19.4% [95%CI: 18.0-20.8]; 1.3% [95%CI: 0.09-1.7]), urban MVIP cohort (16.2 [95%CI: 15.0-18.5]; 1.5% [95%CI: 0.9-0.2], and lowest in the regional MVIP cohort (13.6% [95%CI: 113-16.2]; 0.7% [95%CI: 0.0-1.3],).

As urban residence has been found to be a risk factor for myopia,[17] we stratified participants by regional/urban residence. Compared to the regional MVIP cohort (n=700), the BHAS cohort had a higher age-standardised prevalence of myopia (13.8% vs 19.4%, p=0.001), but there was no significant difference in high myopia (0.7% vs 1.3%, p=0.26). G1RS participants had a higher age-standardised prevalence of any myopia and high myopia compared to urban MVIP participants (any myopia: 16.4% vs 29.2%, p<0.001; high myopia: 1.5% vs 3.9%, p<0.001) and a higher age-standardised prevalence of any myopia, but not high myopia, compared to BMES participants (any myopia: 23.9% vs 29.2%, p=0.004; high myopia: 2.7% vs 3.9%, p=0.12).

Table 2 shows the odds of myopia (≤-0.50 D) or high myopia (≤-5.00 D) after adjusting for age, sex, post-school educational status and urban/regional residence. Younger age and a post-secondary school education were both significantly associated with increased risk of any myopia and high myopia. Supplementary Fig 1 shows the prevalence of myopia and high myopia stratified by post-school education. Female sex was associated with higher odds of high myopia, but not any myopia, and urban residence was not significantly associated with either any myopia or high myopia. Similar to unadjusted comparisons, G1RS participants had the highest odds of myopia, while MVIP participants had the lowest odds and there was no significant difference between BMES and BHAS participants. G1RS participants had significantly higher odds of high myopia compared to MVIP participants (odds ratio [OR]=1.85, 95%CI: 1.06, 3.24) but there were no significant differences in odds of myopia between BMES or BHAS participants and MVIP or G1RS participants.

Table 2: Multivariable logistic regression models investigating variables associated with risk of myopia (≤-0.50 D) and high myopia (≤-5.00 D) stratified by urban/rural cohort

	Odds ratio for myopia (95% CI)	p	Odds ratio for high myopia (95% CI)	p
Urban studies				
BMES	Reference		Reference	
MVIP	0.67 (0.56, 0.80)	<0.001	0.71 (0.43, 1.18)	0.19
G1RS	1.34 (1.10, 1.62)	0.003	1.30 (0.88, 2.25)	0.16
Age (years)	0.95 (0.93, 0.96)	<0.001	0.97 (0.94, 1.00)	0.09
Sex (reference = male)	0.97 (0.84, 1.12)	0.70	1.94 (1.29, 2.93)	0.002
Post-school qualification (reference = no)	1.12 (0.96, 1.31)	0.15	1.87 (1.21, 2.88)	0.005
Regional Studies				
MVIP	Reference		Reference	
BHAS	1.42 (1.12, 1.81)	0.004	1.42 (0.55, 3.66)	0.47
Age (years)	0.96 (0.94, 0.97)	<0.001	0.95 (0.90, 1.00)	0.07
Sex (reference = male)	0.96 (0.81, 1.14)	0.63	1.57 (0.84, 2.97)	0.16
Post-school qualification (reference = no)	1.33 (1.12, 1.58)	0.001	2.80 (1.42, 5.52)	0.003

Separate multivariable logistic regression models run for urban and regional studies. All variables listed included as explanatory variables in a single model with myopia or high myopia as the outcome.

95% CI=95% confidence interval; BMES=Blue Mountains Eye Study; MVIP=Melbourne Visual Impairment Project; G1RS=Generation 1 Raine Study; BHAS=Busselton Healthy Ageing Study

4. DISCUSSION

This study sought to assess the current prevalence of myopia and compare age-matched contemporary and earlier studies to identify any trends of a myopia epidemic in Australia. The prevalence of myopia varied from approximately 16% in the MVIP to approximately 30% in the G1RS. When stratified by regional/urban location, the more recent studies had a significantly higher prevalence of myopia than the earlier studies. Compared to the UK Biobank, urban G1RS participants had a similar prevalence of myopia but a lower prevalence of high myopia, while all other studies had a lower prevalence compared to their UK counterparts.
Environmental changes may explain the increase in rates of myopia noted in this study. Two well-associated risk factors for myopia — educational attainment and time spent outdoors — have changed over generations. Higher level of education is a known risk factor for myopia,[9,12] and the proportion of the population achieving a secondary school education or a university degree or higher has been increasing in Australia since the 1940s.[18] G1RS had a high proportion of participants with a post-school education and this cohort is known to have higher educational attainment than the general Western Australian population.[15] The studies in this analysis with the highest proportions of participants achieving a post-school qualification also had the highest prevalence of myopia. Similar to a study of European adults,[5] we found that education explained some of the variance in myopia prevalence but the differences in the frequency of myopia between the cohorts remained after adjusting for this measure.

Spending more time outdoors reduces the risk of developing myopia.[19] It is possible that the amount of time spent outside has decreased between successive generations, thus causing an increase in myopia prevalence. Indirect evidence of this change may come from lower rates of pterygium excision, a sun-related eye condition, in Australian adults over the last 40 years.[20] However, this decrease could equally reflect less time spent outdoors or improved ultraviolet radiation protection, i.e. more individuals wearing sunglasses. Further indirect evidence of a decrease in time spent outside over generations may come from the increased levels of educational attainment, suggesting that young people are spending more time in the educational system and studying indoors rather than spending time outside and the recent COVID-19 pandemic lockdowns are likely to have exacerbated this trend.

The increase in myopia rates between the earlier and contemporary cohorts of 5 to 13% over approximately 20 years is greater than those seen in Europe.[21] This faster increase in myopia prevalence in Australia may partly be driven by the higher proportion of participants with post-school education in the current study relative to Europe. In Williams et al.'s report which compared earlier and later European cohorts about 12-15% of their earlier cohort (born 1910-1939) and 25-50% of their later cohort (born 1940-1979) had a post-school education, compared to 26-59% and 49-77% in our current for the earlier and contemporary cohorts.

However, Australia still has a smaller increase in myopia prevalence compared to those seen in East Asian populations.[22] The more rapid growth in myopia rates are not only observed in East Asian countries, but may also be seen in individuals of East Asian descent living in Australia. The Sydney Myopia Study reported that children of East Asian descent were at higher risk of incident myopia compared to those of European ancestry.[23] Further studies need to be undertaken to quantify the increase in myopia rates in Australia adults of Asian or East Asian descent. Moreover, because of the rise in migrants from East Asians countries to Australia in recent decades, the true increase in myopia prevalence in the general population of Australians is very likely higher than our current estimation as our samples comprise predominantly European adults. Although our study indicates an increase in myopia rates from pre-war born Australians to Baby boomer Australians we expect to see far greater increases in the subsequent generations, where we expect the high rates of myopia in school leavers to continue to increase through early adulthood. Unfortunately, the largest community-based study in Australia, the National Eye Health Study,[24] did not collect refractive data on all participants and had a major focus on the Aboriginal population and the causes of blindness. Future population-based surveys in Australia should aim to obtain more data on refractive error and all the associated risks for blinding eye diseases in Australians of East Asian and other ancestries. Researchers should build upon the baseline data of the Sydney Myopia Study and the Sydney Adolescent Vascular and Eye Study to address the differential rates of increase in myopia prevalence between ethnicities in Australia.

A number of limitations of this analysis should be considered. First, there were geographic differences in our study that may be associated with myopia prevalence. For example, the prevalence of myopia was approximately 30% in 17-year-old students in Sydney[25] vs 23% in 20-year-old adults in Perth,[26] although some of this difference may be explained by the greater proportion of individuals of East Asian ancestry in the Sydney sample. Western Australians may therefore have a generally lower prevalence of myopia than counterparts from New South Wales or Victoria, thus we may have underestimated any Australia-wide increases in the prevalence of myopia.

Furthermore, methods for measuring refractive error in population-based studies have changed substantially over time. Some studies have previously estimated the prevalence of myopia based on uncorrected VA in young adults.[4] The quality of autorefraction has improved over time and is now considered standard practice for measuring refractive error in epidemiological and clinical studies of myopia.[27] While all BMES, BHAS and G1RS participants had autorefraction, we were unable to obtain the autorefractor results from the MVIP and thus had to use their vertometry or subjective refraction measures to quantify refractive error. When following the same protocol as the MVIP, the prevalence of myopia in the BMES was found to be approximately 16%,[9] compared to the estimated prevalence of 21% based on autorefraction alone in this study. Thus, use of autorefraction in the BMES, G1RS, and BHAS may have slightly overestimated the prevalence of myopia, relative to the MVIP. Moreover, cycloplegia was performed in the BHAS cohort, which was not done for the other three studies. Although cycloplegia would have been ideal it was not available in all cases. Nonetheless, almost all of our participants are 50 years or older, an age around which accommodation peters out and cycloplegia is considered less important.[28,29] However, our previous twin study[30] suggests that there may be an approximately -0.38 D myopic shift with cycloplegia in older adults (opposite effect of children). Thus, the prevalence of myopia in the BHAS cohort may have been slightly overestimated.

Another challenge was accounting for changes in cataract and refractive surgery over time. While the incidence of cataract development could be presumed to be unchanged, the threshold of visual loss for performing cataract surgery has reduced as the procedure has become safer and therefore fewer older Australians are living with early cataract. Data from the BMES suggest that those with myopia are at higher risk of cataract and thus will be preferentially excluded from the analysis.[31] Hence, excluding only participants who have had cataract surgery is likely to lower the estimate of the prevalence of myopia. To avoid the bias introduced by changing thresholds for cataract surgery, we excluded all participants with a diagnosis of cataract. This will further help to mitigate any impact of nuclear sclerosis-induced myopic shifts in refraction. We also noted that more participants from the G1RS cohort (n=18) had undergone laser refractive surgery compared to the other cohorts (BHAS n=1, others n=0). This may be partly because of the increase in awareness and utilisation of refractive surgery in the past 20 years. However, there was a difference between the two contemporary cohorts as well because the G1RS had a specific question regarding refractive surgery in the questionnaires, but the other studies did not. The difference could also partly stem from the location of the studies, where the participants in the urban location (G1RS) may be more likely to undergo elective surgery than regional participants.

Changes in myopia rates, using earlier cohorts as a comparison, are difficult to measure accurately. Moreover, the sample size for the regional MVIP and G1RS cohorts were relatively small (n= 700 and 756, respectively). Nonetheless, the data presented here suggests Australian myopia rates in older adults are rising from a historically low rate but not at the alarming rate seen in East Asia. The data presented in this study also provides a comparison for future population-based studies of this age group, such as the National Eye Health Survey. However, to avoid potential bias associated with excluding participants with cataract, future studies of younger adults, e.g. school leavers and university entrants, are required to assess changing trends in myopia prevalence. Ongoing monitoring and amelioration of myopia and myopiagenic risk factors are required to prevent future blindness and burden of pathological myopia diseases.

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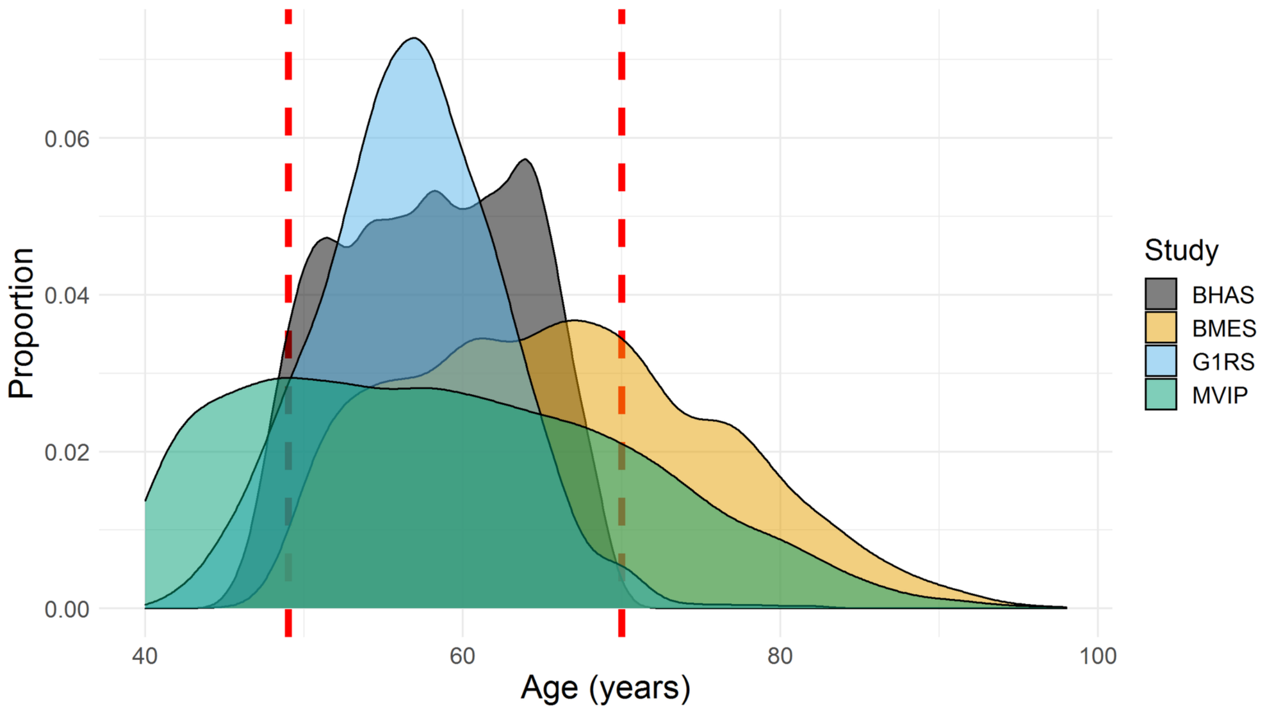
REFERENCES

1. Haarman AEG, Enthoven CA, Tideman JWL, Tedja MS, Verhoeven VJM, Klaver CCW. The Complications of Myopia: A Review and Meta-Analysis. *Invest Ophthalmol Vis Sci.* 2020;61(4):49.
2. Holden BA, Fricke TR, Wilson DA, et al. Global Prevalence of Myopia and High Myopia and Temporal Trends from 2000 through 2050. *Ophthalmology.* 2016;123(5):1036-1042.
3. Cameron AJ, Welborn TA, Zimmet PZ, et al. Overweight and obesity in Australia: the 1999-2000 Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Med J Aust.* 2003;178(9):427-432.
4. Dolgin E. The myopia boom. *Nature.* 2015;519(7543):276-278.
5. Williams KM, Bertelsen G, Cumberland P, et al. Increasing prevalence of myopia in Europe and the impact of education. *Ophthalmology.* 2015;122(7):1489-1497.
6. Vitale S, Sperduto RD, Ferris FL, 3rd. Increased prevalence of myopia in the United States between 1971-1972 and 1999-2004. *Archives of ophthalmology.* 2009;127(12):1632-1639.
7. Mitchell P, Smith W, Attebo K, Wang JJ. Prevalence of age-related maculopathy in Australia. The Blue Mountains Eye Study. *Ophthalmology.* 1995;102(10):1450-1460.
8. Lim R, Mitchell P, Cumming RG. Refractive associations with cataract: the Blue Mountains Eye Study. *Invest Ophthalmol Vis Sci.* 1999;40(12):3021-3026.
9. Attebo K, Ivers RQ, Mitchell P. Refractive errors in an older population: the Blue Mountains Eye Study. *Ophthalmology.* 1999;106(6):1066-1072.
10. Livingston PM, Carson CA, Stanislavsky YL, Lee SE, Guest CS, Taylor HR. Methods for a population-based study of eye disease: the Melbourne Visual Impairment Project. *Ophthalmic Epidemiol.* 1994;1(3):139-148.
11. McKay R, McCarty CA, Taylor HR. Diabetic retinopathy in Victoria, Australia: the Visual Impairment Project. *Br J Ophthalmol.* 2000;84(8):865-870.

12. Wensor M, McCarty CA, Taylor HR. Prevalence and risk factors of myopia in Victoria, Australia. *Archives of ophthalmology.* 1999;117(5):658-663.
13. Taylor HR, West SK. The clinical grading of lens opacities. *Aust N Z J Ophthalmol.* 1989;17(1):81-86.
14. James A, Hunter M, Straker L, et al. Rationale, design and methods for a community-based study of clustering and cumulative effects of chronic disease processes and their effects on ageing: the Busselton healthy ageing study. *BMC Public Health.* 2013;13:936.
15. Dontje ML, Eastwood P, Straker L. Western Australian pregnancy cohort (Raine) Study: Generation 1. *BMJ Open.* 2019;9(5):e026276.
16. Cumberland PM, Bao Y, Hysi PG, et al. Frequency and Distribution of Refractive Error in Adult Life: Methodology and Findings of the UK Biobank Study. *PLoS One.* 2015;10(10):e0139780.
17. Ip JM, Rose KA, Morgan IG, Burlutsky G, Mitchell P. Myopia and the urban environment: findings in a sample of 12-year-old Australian school children. *Invest Ophthalmol Vis Sci.* 2008;49(9):3858-3863.
18. Tunny G. Educational attainment in Australia. Department of the Treasury. https://treasury.gov.au/publication/economic-roundup-autumn-2006/educational-attainment-in-australia. Published 2006. Accessed 27 November 2020.
19. Xiong S, Sankaridurg P, Naduvilath T, et al. Time spent in outdoor activities in relation to myopia prevention and control: a meta-analysis and systematic review. *Acta ophthalmologica.* 2017;95(6):551-566.
20. Stevenson LJ, Mackey DA, Lingham G, et al. Has the Sun Protection Campaign in Australia Reduced the Need for Pterygium Surgery Nationally? *Ophthalmic Epidemiol.* 2020:1-9.
21. Williams KM, Verhoeven VJ, Cumberland P, et al. Prevalence of refractive error in Europe: the European Eye Epidemiology (E(3)) Consortium. *Eur J Epidemiol.* 2015;30(4):305-315.
22. Rudnicka AR, Kapetanakis VV, Wathern AK, et al. Global variations and time trends in the prevalence of childhood myopia, a systematic review and

quantitative meta-analysis: implications for aetiology and early prevention. *The British journal of ophthalmology.* 2016;100(7):882-890.

23. French AN, Morgan IG, Mitchell P, Rose KA. Risk factors for incident myopia in Australian schoolchildren: the Sydney adolescent vascular and eye study. *Ophthalmology.* 2013;120(10):2100-2108.
24. Foreman J, Keel S, McGuiness M, et al. Future burden of vision loss in Australia: Projections from the National Eye Health Survey. *Clin Exp Ophthalmol.* 2020;48(6):730-738.
25. French AN, Morgan IG, Burlutsky G, Mitchell P, Rose KA. Prevalence and 5- to 6-year incidence and progression of myopia and hyperopia in Australian schoolchildren. *Ophthalmology.* 2013;120(7):1482-1491.
26. McKnight CM, Sherwin JC, Yazar S, et al. Myopia in young adults is inversely related to an objective marker of ocular sun exposure: the Western Australian Raine cohort study. *American journal of ophthalmology.* 2014;158(5):1079-1085.
27. Hashemi H, Khabazkhoob M, Asharlous A, et al. Cycloplegic autorefraction versus subjective refraction: the Tehran Eye Study. *Br J Ophthalmol.* 2016;100(8):1122-1127.
28. Fotouhi A, Morgan IG, Iribarren R, Khabazkhoob M, Hashemi H. Validity of noncycloplegic refraction in the assessment of refractive errors: the Tehran Eye Study. *Acta ophthalmologica.* 2012;90(4):380-386.
29. Jan C, Congdon N, Zhou W, Ross B, Wang N, Liang Y. The value of cycloplegia in optometric refraction of adults in a population study. *Acta ophthalmologica.* 2019;97(3):e484-e486.
30. Toh T, Kearns LS, Scotter LW, Mackey DA. Post-cycloplegia myopic shift in an older population. *Ophthalmic Epidemiol.* 2005;12(3):215-219.
31. Kanthan GL, Mitchell P, Rochtchina E, Cumming RG, Wang JJ. Myopia and the long-term incidence of cataract and cataract surgery: the Blue Mountains Eye Study. *Clin Exp Ophthalmol.* 2014;42(4):347-353.



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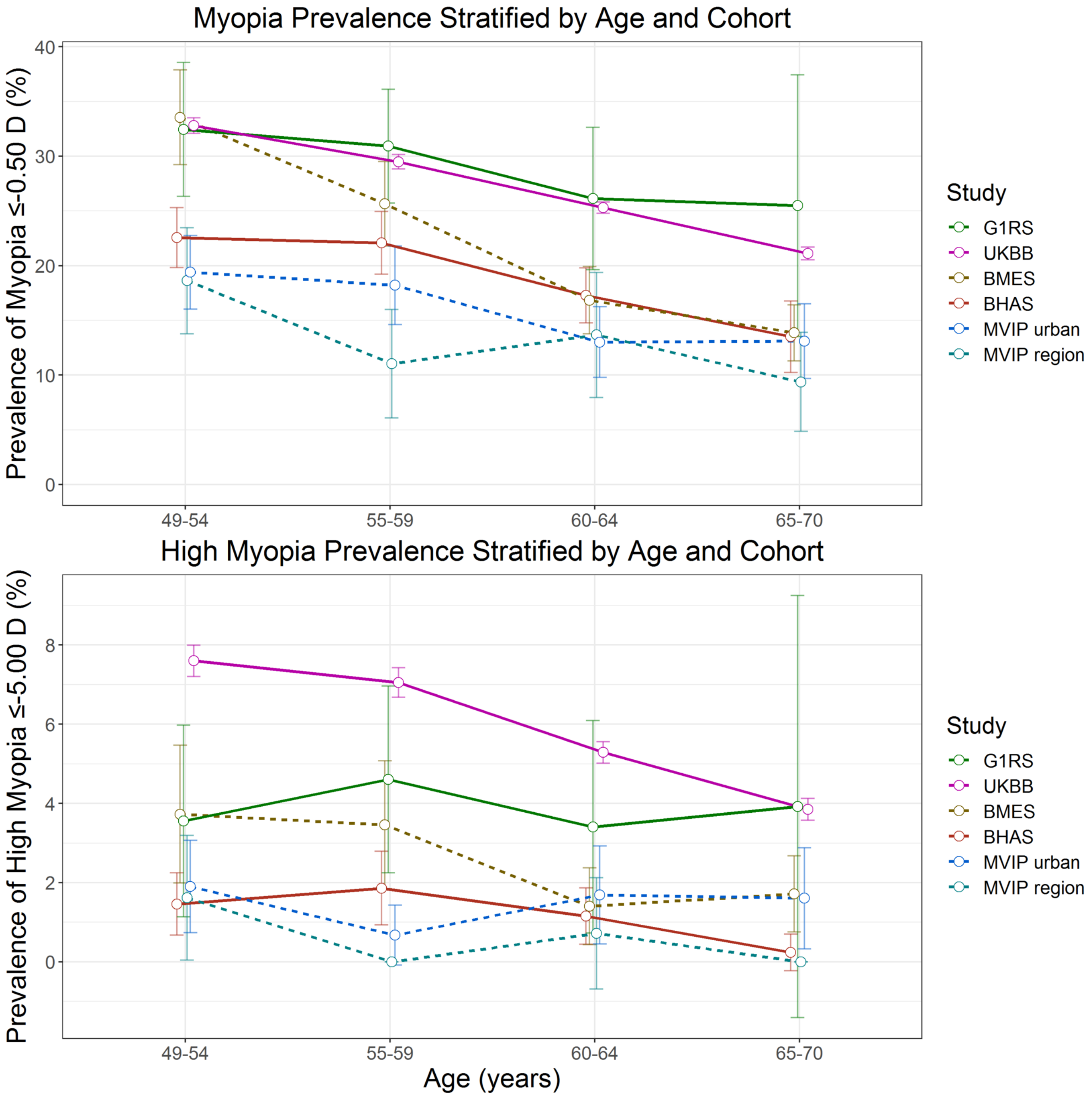

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