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Vinay Kumar Nilagiri
University of Western Australia, Australia

Samantha Sze-Yee Lee
University of Western Australia, Australia

Gareth Lingham
Technological University Dublin, gareth.lingham@tudublin.ie

See next page for additional authors

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Refractive Intervention

Distribution of Axial Length in Australians of Different Age Groups, Ethnicities, and Refractive Errors

Vinay Kumar Nilagiri[1], Samantha Sze-Yee Lee[1], Gareth Lingham[1,3], Jason Charng[1,2], Seyhan Yazar[4], Alex W. Hewitt[5,7], Lyn R. Griffiths[6], Paul G. Sanfilippo[7], Tzu-Hsun Tsai[8], and David A. Mackey[1,5]

[1] Centre for Ophthalmology and Visual Science (incorporating the Lions Eye Institute), University of Western Australia, Perth, Western Australia, Australia
[2] Department of Optometry, School of Allied Health, University of Western Australia, Perth, Western Australia, Australia
[3] Centre for Eye Research Ireland, School of Physics, Clinical and Optometric Sciences, Technological University Dublin, Dublin, Ireland
[4] Garvan-Weizmann Centre for Cellular Genomics, Garvan Institute of Medical Research, Sydney, Australia
[5] School of Medicine, Menzies Research Institute Tasmania, University of Tasmania, Tasmania, Australia
[6] Genomics Research Centre, Centre for Genomics and Personalised Health, School of Biomedical Sciences, Queensland University of Technology, Queensland, Australia
[7] Centre for Eye Research Australia, University of Melbourne, Department of Ophthalmology, Royal Victorian Eye and Ear Hospital, Melbourne, Victoria, Australia
[8] Department of Ophthalmology, National Taiwan University Hospital Hsin-Chu Branch, Hsin-Chu, Taiwan

Correspondence: David A. Mackey, Lions Eye Institute, 2 Verdun St, Nedlands, WA 6009, Australia.
e-mail: david.mackey@lei.org.au

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Purpose: Treatments are available to slow myopic axial elongation. Understanding normal axial length (AL) distributions will assist clinicians in choosing appropriate treatment for myopia. We report the distribution of AL in Australians of different age groups and refractive errors.

Methods: Retrospectively collected spherical equivalent refraction (SER) and AL data of 5938 individuals aged 5 to 89 years from 8 Australian studies were included. Based on the SER, participants were classified as emmetropes, myopes, and hyperopes. Two regression model parameterizations (piece-wise and restricted cubic splines [RCS]) were applied to the cross-sectional data to analyze the association between age and AL. These results were compared with longitudinal data from the Raine Study where the AL was measured at age 20 (baseline) and 28 years.

Results: A piece-wise regression model (with 1 knot) showed that myopes had a greater increase in AL before 18 years by 0.119 mm/year ($P < 0.001$) and after 18 years by 0.011 mm/year ($P < 0.001$) compared to emmetropes and hyperopes, with the RCS model (with 3 knots) showing similar results. The longitudinal data from the Raine Study revealed that, when compared to emmetropes, only myopes showed a significant change in the AL in young adulthood (by 0.016 mm/year, $P < 0.001$).

Conclusions: The AL of myopic eyes increases more rapidly in childhood and slightly in early adulthood. Further studies of longitudinal changes in AL, particularly in childhood, are required to guide myopia interventions.

Translational Relevance: The axial length of myopic eyes increases rapidly in childhood, and there is a minimal increase in the axial length in non-myopic eyes after 18 years of age.

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Introduction

Axial length (AL) is one of the important parameters that determines the refractive power of the eye. AL increases rapidly during the first few years of life after birth and typically stabilizes during the second decade of life.[1,2] At birth, AL is approximately 16.8 mm and generally increases to 23.6 mm in young adulthood.[3] Excessive axial elongation results in myopia refractive error.

Myopia is one of the leading causes of visual impairment around the world, and it is estimated that by year 2050, nearly half of the world's population will have myopia.[4] Myopia carries an increased risk of other ocular complications, such as glaucoma, cataract, retinal detachment, and pathological myopia.[5] These conditions can lead to irreversible visual impairment and blindness. Thus, limiting the progression of myopia can preserve vision. The rate of myopia progression is also dependent on the age of onset and the severity of myopia.[6,7] Ethnicity has also been shown to affect prevalence of myopia as East Asians tend to have longer eyes compared to Europeans and Africans.[8–10] Recently, ethnicity and age-specific percentile charts for AL were developed for myopia screening.[11–14] AL measurements are highly repeatable[15–17] and are becoming increasingly relevant to determine myopia progression and to monitor myopia in younger children. Therefore, having population-based normative values will be useful in choosing appropriate treatment strategies to limit myopia progression.

Reports on the distribution of AL with increasing age in adults have been inconsistent. Some studies[18,19] have reported an increase in AL whereas a few other studies[20,21] have reported a reduction in AL with age. For example, Atchison et al.[22] showed an increase in the AL of 0.011 mm per year in emmetropes between 18 and 69 years of age. The Blue Mountains Eye Study,[23] which involved an older population aged between 59 and 85 years, reported a reduction in AL of 0.12 mm per decade in women and 0.02 mm per decade in men. Another study by Foster et al.[19] in an older age group (60 and 80 years of age) reported a decrease in AL of 0.10 mm per decade in men and 0.09 mm per decade in women. However, some other studies[24–26] have reported no change in AL with age. Recently, a systematic review by Rozema et al.[27] investigated the discrepancies in AL with age and concluded that the age-related decrease in AL is associated with increased height and education level in the younger generations, although there was a minor influence of lens thickness, measurement procedure, and thinning of the choroidal arteries on the AL. The differences in these findings may influence the selection and application of treatment strategies, especially while considering the population- and age-based reference values.

Previous studies have reported the AL distribution in either children[28,29] or adults[21] but not both in the same study. There is a lack of information in the literature on the distribution of AL in a wide range of age groups in the Australian population. Given the role of ethnicity in myopia, data on AL could help clinicians identify individuals at risk of myopia and then choose appropriate anti-myopia strategies. The purpose of this study was to report the distribution of AL in Australians of different groups and ethnicities and a range of refractive errors.

Methods

Study Sample

This retrospective study included participants from eight studies: the Australian Twins Eye Studies in Tasmania and Brisbane, the Western Australia Twins Eye Study, the Kidskin Study, the Raine Study Gen2, the Raine Study Gen1 (parents of Gen 2), the Norfolk Island Eye Study, and the Eye Protection Study. The detailed methodologies of each study have been published previously.[30–33] All eight studies were conducted in accordance with the tenets of Declaration of Helsinki, and the ethics approvals were obtained from the Royal Victorian Eye and Ear Hospital, the University of Tasmania, the Australian Twin Registry, and the Queensland Institute of Medical Research, Griffith University, and subsequently Queensland University of Technology, and the University of Western Australia's Human Research Ethics Committees.

The Twin Eye Studies in Tasmania and Brisbane[30] were initiated in 2000 and recruited participants aged 5 to 90 years in 7 phases. This population-based cohort study was conducted to identify genes responsible for the development of glaucoma, using twin siblings as a model to understand the correlation and covariance of phenotypes within the monozygotic and dizygotic twin pairs to estimate the heritability of a trait. All participants underwent a comprehensive eye examination.

The Western Australia Twins Eye Study was a registry-based study that investigated the influence of genetics and environmental factors on ocular traits related to glaucoma. A total of 79 participants were examined.

The Kidskin Study[32] was a nonrandomized control trial that investigated the effects of sun exposure in

5- to 6-year-old children in Western Australia in 1995. A follow-up of the Kidskin Study was conducted between May 2015 and March 2019 and these participants were invited to attend a comprehensive eye examination (25–30 years of age at the time of eye examination).

The Raine Study[33] is an ongoing multi-generational longitudinal study that has been following a cohort from in utero between 1989 and 1991. These participants have been undergoing a series of medical and health assessments at various time points. At the 20-year follow-up of the study, conducted between March 2010 and February 2012, the Generation 2 study participants underwent a comprehensive eye examination. A further follow-up study was conducted when the Generation 2 participants were 28 years old. The Raine Study Generation 1 comprises the parents of the Raine Study Generation 2 participants. Generation 1 participants were examined between 2014 and 2017 when they were 40 to 81 years old.

The Norfolk Island Eye Study[31] was a population-based study conducted between November 2007 and February 2008 to identify eye disease-causing genes. The Norfolk Island's population comprises descendants of Europeans and Polynesians who were resettled there. Therefore, the island's population has a blend of European and Polynesian heritage. In this study, all participants received a comprehensive eye examination.

The Eye Protection Study[34] investigated the risk factors associated with sports-related eye injuries in Western Australia. Participants aged between 17 and 60 years were included.

The number of participants included from each study is shown in Figure 1. Overall, 5938 participants' data were included from 8 studies, of which 5211 participants' data were included in the cross-sectional data analysis. The remaining 727 participants' data from the Raine Study Gen2–28 year follow-up was used for the longitudinal analysis. A total of 432 participants data were excluded from the analysis as 261 had missing data on refractive error or axial length, 86 underwent cataract surgery, 52 underwent refractive surgery, 9 had corneal disease or surgery, 6 had glaucoma disease or surgery, and 18 had retinal disease or surgery.

In all studies, participants' cycloplegic autorefraction was measured using the Nidek autorefractometer (Nidek ARK-510 A, Nidek, Japan) and ocular biometry was performed using the IOL Master (version 5; Carl Zeiss Meditec AG, Jena, Germany).

The required variables, such as age, sex, spherical equivalent refraction (SER), AL, and ethnicity, were extracted. The ethnicity data were classified as Europeans, European-Polynesian (Norfolk Islanders), East Asian, South Asian, and Other/mixed groups. Participants with missing SER data or AL and individuals with ocular conditions that could influence the AL (e.g. keratoconus, pseudophakia, refractive surgery, and retinal diseases) were excluded.

The SER was defined as the sum of the spherical and half of the cylindrical power. Based on the SER, the data were segregated into emmetropes (+0.50 diopters [D] to ≥0.50 D), myopes (≤–0.50 D), and hyperopes (>+0.50 D). Based on age at the time of examination, all individuals were stratified into age groups in 10-year intervals, except the first age group (e.g. 5–10 years, 11–20 years, etc.).

Statistical Analysis

Statistical analyses were performed using the R studio software (R Foundation for Statistical Programming, r-project.org). The Shapiro-Wilk test indicated that AL data were not normally distributed in different age groups. Therefore, nonparametric statistics were applied. Continuous variables, such as age, SER, and AL, were described using median and interquartile range (IQR). A P value of < 0.05 was considered statistically significant.

The cross-sectional association between AL (outcome) and refractive errors were explored using a linear mixed modeling (LMM) approach adjusting for potential confounders of age, sex, and ethnicity. Both eyes' data were included in the analysis. A random effect and intercept for participants were implemented in the LMMs to account for the within-subject correlation between the two eyes. Nonparametric visualization of the association between age and AL suggested a single inflection point at approximately 18 to 20 years of age, with relatively linear slopes in adjacent age epochs (≤18 vs. >18 years). Thus, we applied a piece-wise regression model with a single knot at 18 years of age to investigate the relationship between age and AL in participants with different refractive errors, assuming linearity between age and AL in each epoch. In a sensitivity analysis, we also modeled this association using restricted cubic splines (RCSs) to fully relax the assumption of linearity between age and AL.

The longitudinal analysis was performed using the Raine Study Gen2–20 year follow-up examination data. In the LMM analysis, in addition to adjusting for age, sex, and ethnicity, the height data measured at the Raine Study Gen2–20 year follow-up examination was also included. As the majority of the participants were Europeans (85.6%), the analysis was performed on European only data and with other ethnic groups'

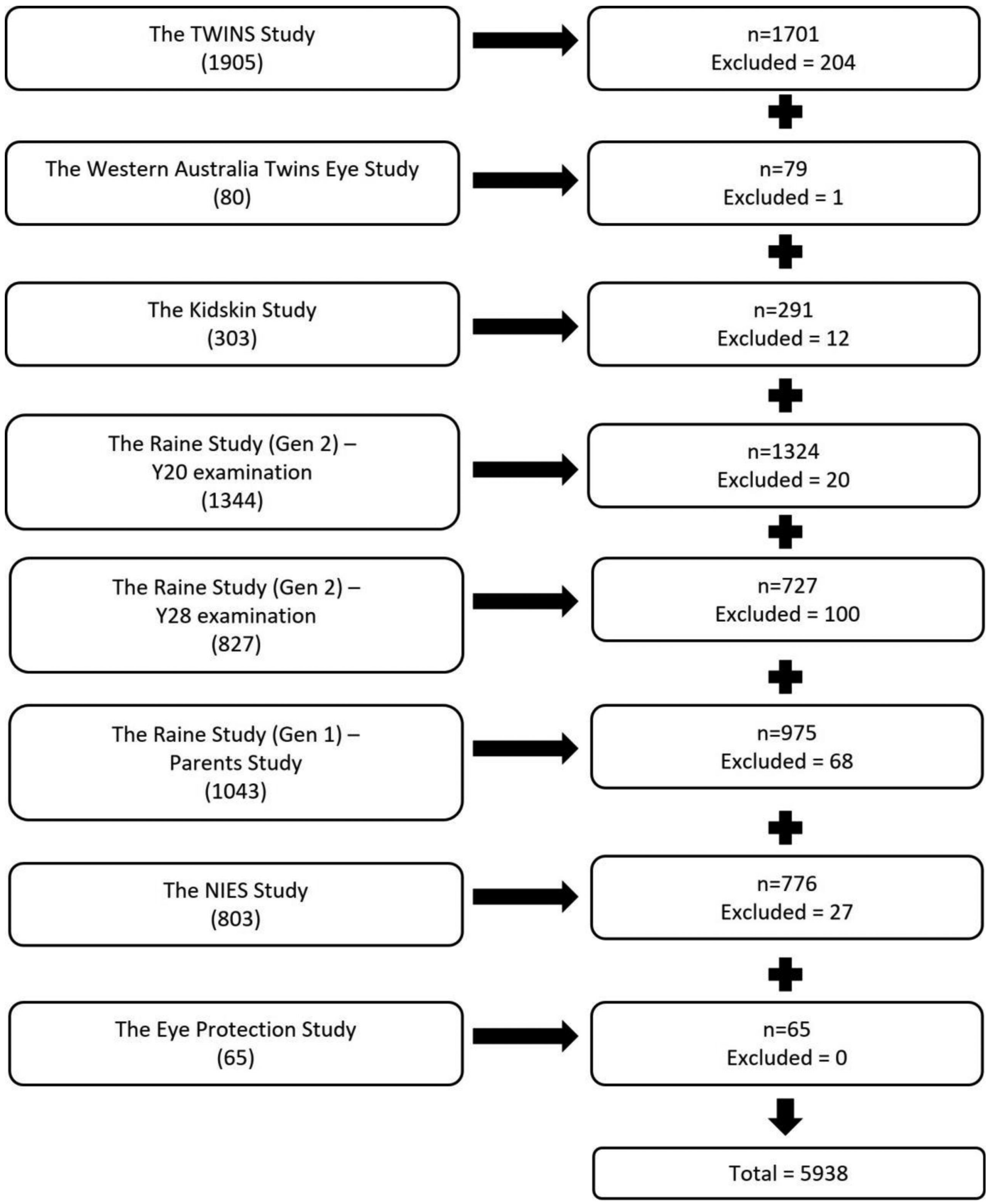

Figure 1. Sample size used from eight studies for the analysis.

data to evaluate if there was a potential influence of other ethnicities on the AL.

Results

The cross-sectional analysis included 5211 participants: 2198 (42.2%) emmetropes, 1487 (28.6%) myopes, and 1526 (29.2%) hyperopes. The overall median (IQR) age was 23.0 (IQR = 19.7–51.0) and SER was +0.13 D (IQR = −0.63 D to +0.63 D). The longitudinal analysis included 727 participants: 339 (46.7%) were emmetropes, 178 (24.5%) myopes, and 210 (28.8%) hyperopes at the baseline visit. The overall median (IQR) age was 24.6 years (IQR = 19.9–28.1 years) and SER was +0.25 D (IQR = −0.50 D to +0.63 D).

In emmetropes the overall median (IQR) age was 21.0 years (IQR = 19.6–43.0 years), 1143 were women (52.0%), and SER was +0.13 D (IQR= −0.13 D to +0.38 D). In myopes, the overall median age was 24.0 years (IQR = 20.0–51.0 years), 899 were women (60%), and SER was −1.25 D (IQR = −2.50 D to −0.75 D). In hyperopes, the overall median age was 26.0 years (IQR = 19.7–56.0 years), 826 were women (54%), and

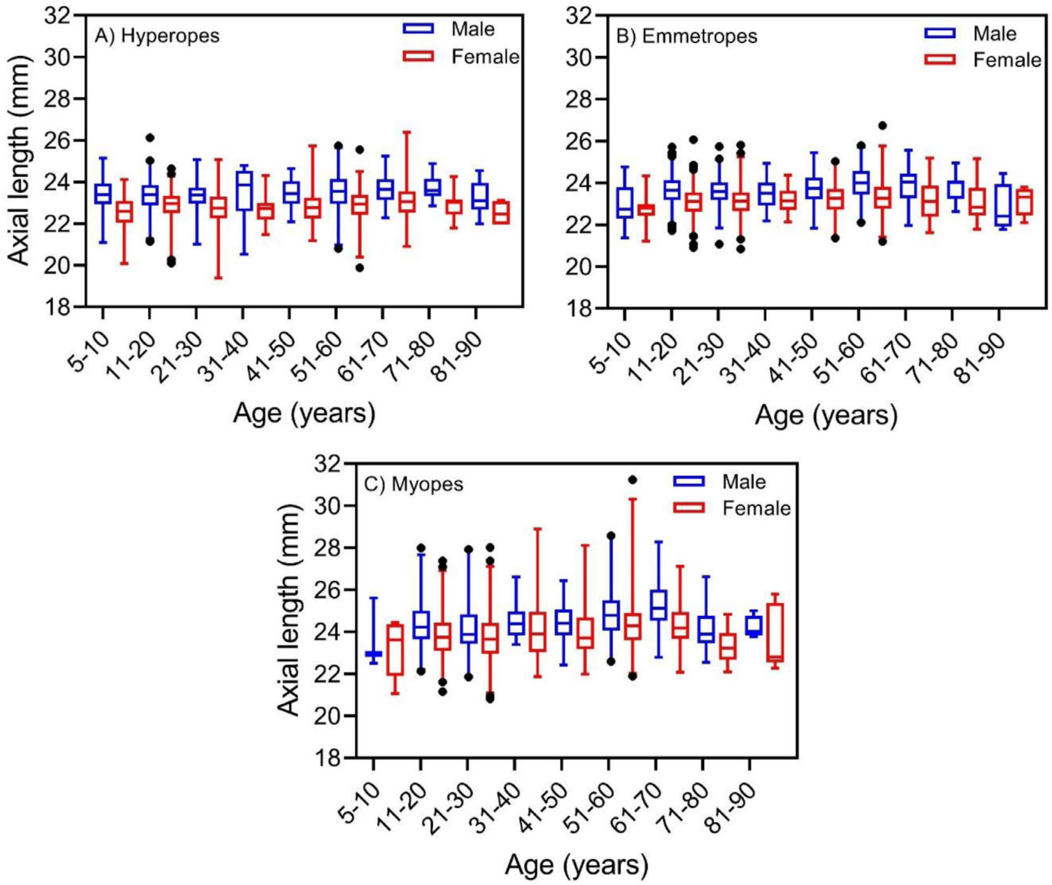

Figure 2. Box and Whisker plots of axial length based on sex in hyperopes, emmetropes, and myopes. The *solid horizontal line in the box* indicates median value; *lower and upper edges of the box* indicate 25th and 75th interquartile range (IQR); *lower and upper whisker* show the 1st and 99th quartiles and the *black dark circles* indicate outliers.

SER was +1.00 D (IQR= +0.75 D to +1.38 D). The overall median (IQR) AL was 23.38 mm (IQR = 22.84–23.90) in emmetropes; 23.91 mm (IQR = 23.26–24.78) in myopes; and 23.12 mm (IQR = 22.62–23.64) in hyperopes, respectively (Fig. 2).

The results of the piece-wise regression model are shown in Table 1, with post hoc slope estimation of age for the different refractive cohorts in Table 2 and visualization of the age- and cohort-dependent relationships in Figure 3a. The slope for age in those aged 18 or younger was estimated to be 0.045 (95% confidence interval [CI] = 0.024, 0.054, $P < 0.001$) reflecting the average yearly increase in AL for the emmetrope cohort. As expected, the slope was greater for myopes (0.119 [95% CI = 0.080, 0.157, $P < 0.001$]) and lower for hyperopes (0.013 (95% CI = −0.002, 0.029, P = 0.11)). In older subjects (>18 years), all cohorts showed a pattern of flattening in the association between age and AL, although myopes still demonstrated a slightly greater average yearly increase in AL compared to emmetropes and hyperopes (slope = 0.011 vs. 0.005 and 0.004, respectively). Women had shorter AL by 0.543 mm (95% CI = 0.589, 0.497, $P < 0.001$) compared to men, and East Asians longer AL by 0.538 mm (95% CI = 0.389, 0.688, $P < 0.001$), compared to Europeans.

Figure 3b shows the commensurate plot with the assumption of linearity between AL and age fully relaxed and modelled using RCSs (3 knots). Models with four and five knots were also examined and provided slightly better fits (based on likelihood ratio testing); however, graphing these showed obvious overfitting. Thus, the three-knot model was used. The piecewise model actually provided a better fit than the RCS model when taking into account the additional parameters to allow increased flexibility in the AL-age association. Figures 3a and 3b illustrate this through their similarity. As the coefficients from a model using RCSs are not easily interpretable, estimated marginal means of AL for RCSs and piece-wise models at 5-yearly age increments are shown in Table 3.

Age-wise distribution of AL in men and women of different refractive groups is shown in Supplementary Table S1.

Table 1. Association of Axial Length With Age, Sex, Ethnicity, and Refractive Error Using the Cross-Sectional Data

	Estimate (95% CI)	Standard Error	*P* Value
Age (≤18)	0.045 (0.024 to 0.066)	0.010	<0.001
Age (>18) slope change	–0.040 (–0.061 to –0.018)	0.011	<0.001
Refractive cohort			
Reference: emmetrope			
Hyperope	0.298 (–0.141 to 0.736)	0.224	0.18
Myope	–0.725 (–1.483 to 0.034)	0.387	0.06
Age (≤18) × hyperope	–0.032 (–0.058 to –0.006)	0.013	0.02
Age (≤18) × myope	0.074 (0.030 to 0.117)	0.022	<0.001
Age (>18) slope change × hyperope	0.031 (0.004 to 0.058)	0.014	0.02
Age (>18) slope change × myope	–0.067 (–0.112 to –0.023)	0.023	0.003
Female sex	–0.543 (–0.589 to –0.497)	0.024	<0.001
Ethnicity			
Reference: European			
European/Polynesian	0.029 (–0.043 to 0.101)	0.037	0.42
South Asian	–0.061 (–0.291 to 0.167)	0.117	0.60
East Asian	0.539 (0.389 to 0.688)	0.076	<0.001
Other/mixed	0.358 (0.226 to 0.490)	0.067	<0.001

Table 2. Change in Axial Length (mm) per 1 Year Increase in Age (i.e. Slope) for Subjects Below and Above the Age of 18 Years

Change in Axial Length for 1 y Increase in Age (<18 y)	Estimate (95% CI)	Standard Error	*P* Value
Myopes	0.119 (0.080 to 0.157)	0.019	<0.001
Emmetropes	0.045 (0.024 to 0.066)	0.011	<0.001
Hyperopes	0.013 (−0.002 to 0.029)	0.008	0.11
Change in axial length for 1 y increase in age (>18 y)	**Estimate (95% CI)**	**Standard error**	***P* value**
Myopes	0.011 (0.009 to 0.014)	0.001	<0.001
Emmetropes	0.005 (0.003 to 0.007)	0.001	<0.001
Hyperopes	0.004 (0.002 to 0.007)	0.001	<0.001

In the longitudinal analysis of only Europeans, the LMM analysis revealed that AL increased by 0.012 mm (95% CI = 0.009, 0.015, $P < 0.001$) per year for emmetropes; 0.029 mm (95% CI = 0.012, 0.020, $P < 0.001$) for myopes and 0.005 mm (95% CI = −0.010, −0.003, $P < 0.001$) for hyperopes (Table 4, Fig. 4). In a similar trend to the cross-sectional analysis, women had shorter AL by 0.257 mm on average (95% CI = –0.406, –0.106, $P \leq 0.001$). Height was statistically significantly associated with AL with an average 0.012 mm per 1 cm increase in height (95% CI = 0.006, 0.019, $P < 0.001$; see Table 4). We noted similar results when performing the analysis on all subjects, adjusting for ethnicity. A comparison of regression lines for the cross-sectional and longitudinal data above 18 years is shown in Figure 4.

Discussion

In this study, we reported the change in AL in all refractive groups. The results of this analysis from eight studies across different age groups in Australia indicate that the AL of myopic eyes appears to increase more in childhood and slightly in adult life, whereas the AL of emmetropes and hyperopes seems to stabilize in adult life. The longitudinal data from the Raine Study showed a slightly higher AL, especially for myopes.

The median AL of emmetropes, myopes, and hyperopes reported in this study is similar to the values reported previously in the literature.[20,25,35] Consistent with the previous literature,[22,23,35,36] we found that in all refractive groups, the median AL of women

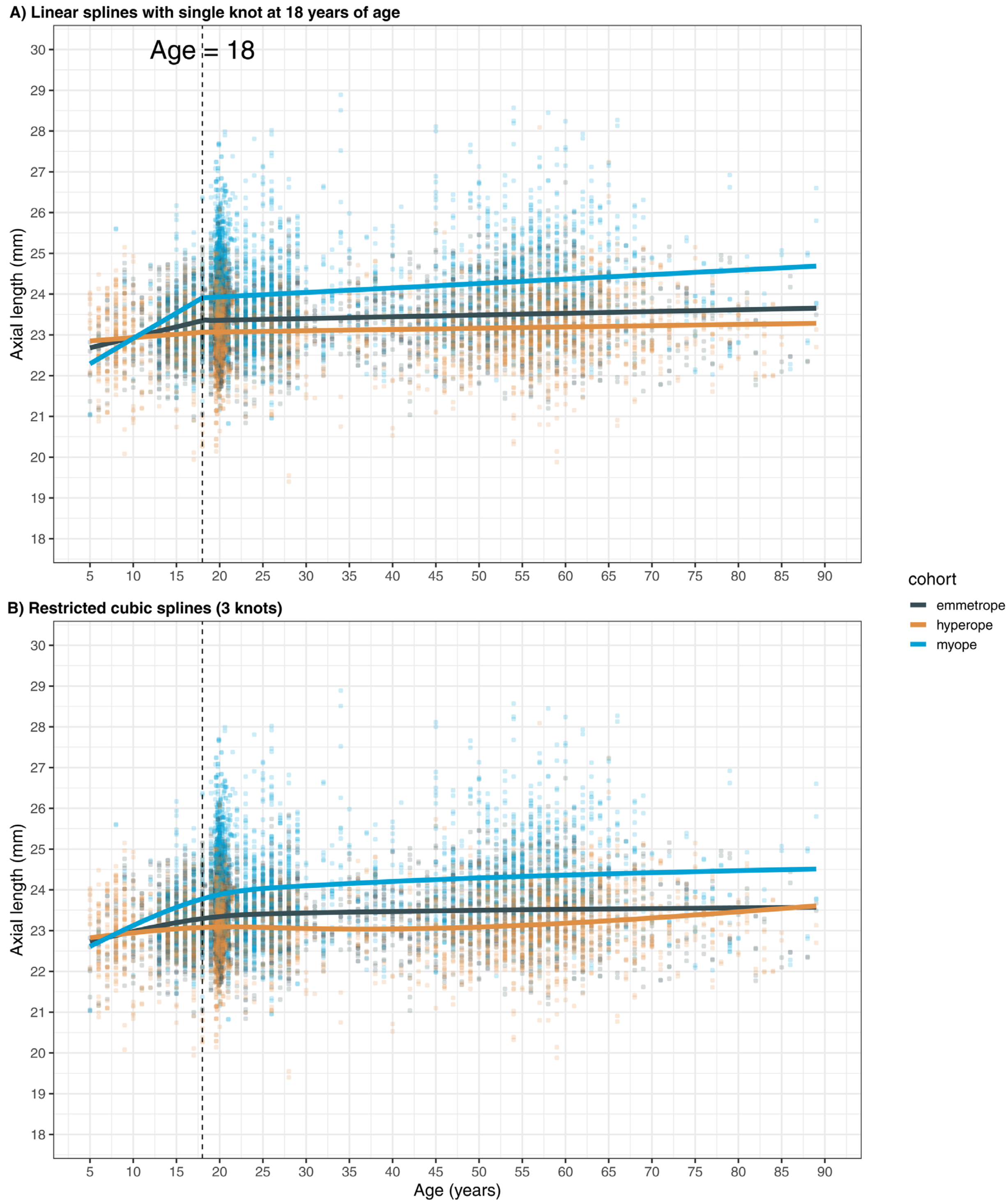

Figure 3. Predictions of AL from: (**A**) linear (piece-wise) and (**B**) restricted cubic spline models.

was shorter than that of men of the same age (see Fig. 2). Although the median AL was shorter for women, there was a large spread of AL data for women, especially in myopes, because of the sample size differences across all age groups. Adjustments for education level, parental myopia, height, and body mass index would have been useful, but that data were not available for participants from all studies and across all age groups. The median AL of myopes was longer than emmetropes and hyperopes, which was consistent across all age groups (see Fig. 2). The outliers in Figure 2, especially in younger age groups, may not

Table 3. Predicted Axial Length (mm) From the Restricted Cubic Splines (RCSs) and Piece-Wise Models at 5 Yearly Intervals

		RCS Model		Piecewise Model	
Refractive Groups	Age (y)	Estimate (95% CI)	Standard Error	Estimate (95% CI)	Standard Error
Emmetrope	5	22.94 (22.67 to 23.21)	0.138	23.37 (23.28 to 23.46)	0.045
Emmetrope	10	23.14 (22.98 to 23.30)	0.081	23.40 (23.32 to 23.49)	0.042
Emmetrope	15	23.32 (23.23 to 23.41)	0.044	23.44 (23.36 to 23.51)	0.039
Emmetrope	20	23.45 (23.38 to 23.52)	0.037	23.47 (23.40 to 23.54)	0.037
Emmetrope	25	23.52 (23.44 to 23.59)	0.036	23.50 (23.44 to 23.57)	0.035
Emmetrope	30	23.55 (23.47 to 23.63)	0.039	23.54 (23.47 to 23.61)	0.034
Hyperope	5	23.00 (22.80 to 23.20)	0.101	23.14 (23.04 to 23.24)	0.050
Hyperope	10	23.08 (22.96 to 23.21)	0.063	23.16 (23.07 to 23.26)	0.047
Hyperope	15	23.15 (23.06 to 23.24)	0.045	23.19 (23.10 to 23.27)	0.044
Hyperope	20	23.19 (23.11 to 23.28)	0.044	23.21 (23.13 to 23.29)	0.041
Hyperope	25	23.21 (23.12 to 23.29)	0.043	23.24 (23.16 to 23.31)	0.040
Hyperope	30	23.21 (23.12 to 23.30)	0.045	23.26 (23.19 to 23.34)	0.038
Myope	5	22.86 (23.38 to 23.34)	0.242	23.86 (23.76 to 23.96)	0.052
Myope	10	23.32 (23.04 to 23.59)	0.141	23.93 (23.84 to 24.02)	0.047
Myope	15	23.75 (23.60 to 23.85)	0.063	24.00 (23.91 to 24.08)	0.044
Myope	20	24.03 (23.95 to 24.11)	0.040	24.07 (23.99 to 24.15)	0.040
Myope	25	24.19 (24.11 to 24.27)	0.040	24.14 (24.06 to 24.21)	0.038
Myope	30	24.29 (24.20 to 24.37)	0.042	24.20 (24.13 to 24.28)	0.036

have skewed the regression analysis because of their proximity to the upper and lower extremes of the data and also because of the large sample size of those age groups.

Below 18 years of age, we found a change in AL of 0.045 mm, 0.013 mm, and 0.119 mm per year increase in age in emmetropes, hyperopes, and myopes, respectively (see Table 2, Fig. 3). Zadnik et al.[37] reported averaged annual AL increase of 0.16 mm per year for age 6 to 9 years, 0.08 mm per year for age 9 to 11 years, and 0.02 mm per year for age group 11 to 14 years in 194 emmetropes. Fledelius et al.[38] reported median AL increase of 0.23 mm per year for age 5 to 7.9 years, 0.15 mm per year for 8 to 9.11 years, 0.09 mm per year for 10 to 13.9 years, 0.08 mm per year for 14 to 15.9 years, and 0.05 mm per year for 16 to 20 years. However, this was reported in a small sample of 78 emmetropes. Previous studies reported change in AL in emmetropes, but not according to different refractive groups.[20,37,38] The rate of change in AL of myopes reported in this study (see Table 3) may not represent all types of myopia, as the myopia progression varies with age, the age of onset of myopia, and severity of myopia.

The AL of older participants reported in this study is in line with the values reported in the literature.[19,23,39,40] Most previous studies that reported AL in older individuals were cross-sectional in nature. The longitudinal Beaver Dam Study[40] reported a decrease in AL by 0.08 mm per 5-year increase in age in older individuals between 65 and 75 years. However, this study included participants with ocular conditions such as cataract and age-related macular degeneration. Another longitudinal study that included only high myopes[41] reported an increase in AL by 0.047 mm per year in individuals between 21 and 57 years. In the current study, we reported an increase in AL of 0.005 mm, 0.004 mm, and 0.011 mm per year increase in age in emmetropes, hyperopes, and myopes, respectively, in individuals between 19 and 89 years (see Table 2, Fig. 3). Recently, a white paper[42] from the International Myopia Institute summarized published data on progression of myopia in young adults and reported annual AL elongation between 0.05 and 0.10 mm/ year, with an average of 0.07 mm/year. In our study, from the Raine Study longitudinal data, we found that the AL of myopes increased by 0.029 mm/year. A previous study[43] from our laboratory reported a similar AL progression of 0.02 mm/year using the same cohort. Unlike the previous studies[44-47] that reported the AL progression mainly in university students or myopic cohorts, the Raine Study participants from our study were community-based young adults generally representative of the Western Australian population of the same age. Addition-

Table 4. Association of Axial Length With Age, Sex, Height, Ethnicity, and Refractive Error Using Longitudinal Data From the Raine Study

	Estimate (95% CI)	Standard Error	*P* Value*
Only Europeans			
Age, y	0.012 (0.009 to 0.015)	0.001	≤0.001
Refractive cohort			
Reference: Emmetrope			
Hyperope	−0.185 (−0.355 to −0.015)	0.087	0.03
Myope	0.543 (0.358 to 0.727)	0.094	≤0.001
Age × hyperope	−0.007 (−0.010 to −0.003)	0.002	≤0.001
Age × myope	0.017 (0.012 to 0.020)	0.002	≤0.001
Female sex	−0.257 (−0.406 to −0.106)	0.077	≤0.001
Height (year 20)	0.012 (0.006 to 0.019)	0.003	≤0.001
Including all Ethnicities			
Age, y	0.013 (0.010 to 0.015)	0.001	<0.001
Refractive cohort			
Reference: Emmetrope			
Hyperope	−0.015 (−0.320 to 0.013)	0.085	0.07
Myope	0.605 (0.430 to 0.781)	0.090	<0.001
Age × hyperope	−0.007 (−0.011 to −0.004)	0.002	<0.001
Age × myope	0.016 (0.012 to 0.020)	0.002	<0.001
Female sex	−0.273 (−0.416 to −0.129)	0.073	<0.001
Height (year 20)	0.012 (0.005 to 0.018)	0.003	<0.001
Ethnicity			
Reference: European			
European/Polynesian	−0.613 (−1.709 to 0.484)	0.562	0.28
South Asian	−0.138 (−0.637 to 0.362)	0.256	0.59
East Asian	0.573 (0.174 to 0.974)	0.205	0.005
Other/mixed	0.254 (0.022 to 0.487)	0.119	0.03

*Multivariate analysis with axial length as the primary outcome adjusting for age, sex, ethnicity, height, and refractive error.

ally, the data from this study support the finding of minimal change in AL, in contrast to some previous cross-sectional studies that reported an increase[18,22] or decrease[19,21,23,26] in AL with age. Although the change in AL was significant in all refractive groups, myopes had a greater change in AL compared to emmetropes and hyperopes. Additionally, we also found that there was variation in the median AL with age in both genders in all refractive groups.

We performed height-adjusted analysis to understand the association between age and AL using the Raine Study Gen2 longitudinal data and found that height was significantly associated with AL (see Table 4), which was consistent with previous studies.[29,48–50]

In our cross-sectional and longitudinal data, we found East Asians had longer AL in all refractive groups compared to other ethnicities, which was consistent with previous literature.[8,51] To eliminate the influence of longer AL of East Asians and other ethnic groups, we performed the analysis separately on Europeans and including all ethnic groups and found a small variation in change of AL with age (see Table 4).

The longitudinal data from the Raine Study Gen2 revealed that those with myopia at baseline had a significant change in AL compared to other refractive groups (see Table 4). The regression lines from the longitudinal data were overlapped onto the cross-sectional data for a visual comparison (see Fig. 3), which showed higher and steeper curves for the longitudinal data, especially for myopes, potentially suggesting generational differences possibly due to the environmental and lifestyle factors for change in AL.

Previous studies have reported AL in either children[28,29,52] or adults[18,19,24] but not both. Although many studies have reported normative data in emmetropes and myopes, data on hyperopes is sparse. In addition, previous studies[23,25,36,50,52] reporting

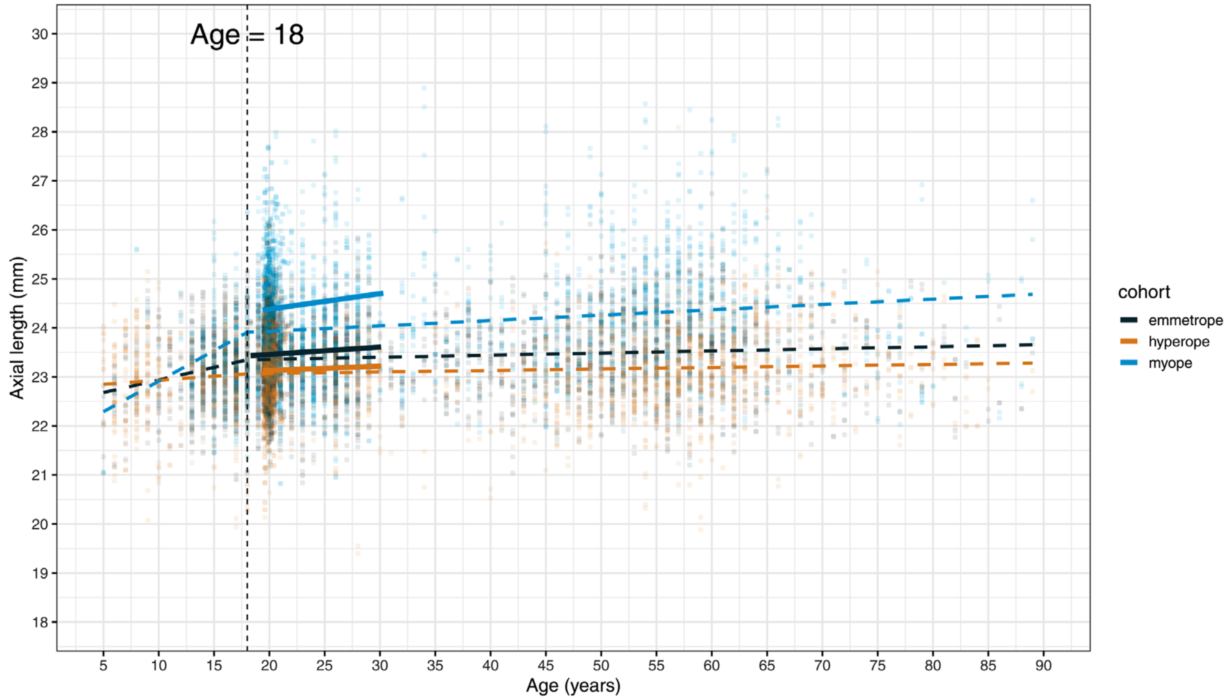

Figure 4. Comparison of the Raine Study longitudinal data (*thick regression lines*) with the cross-sectional data (*dashed regression lines*) from all other studies. The slopes of the cross-sectional and longitudinal data are 0.005 mm, 0.004 mm and 0.011 mm vs. 0.013 mm, 0.006 mm, and 0.029 mm for the emmetropes, hyperopes, and myopes, respectively.

the AL in children or adults had small sample sizes compared to the current study. Addressing that gap, we reported the AL in a wide age range between 5 and 89 years in all refractive groups. The normative AL data of myopes between 5 and 18 years is important in terms of myopia control in children to determine true myopia progression and to differentiate from the natural course of eye growth. The AL change in emmetropes between 5 and 18 years can serve as a clinical reference. The data reported here can serve as a useful reference for clinicians when addressing queries from individuals regarding spectacle prescription change with increasing age based on the change in AL.

Strengths and Limitations

The key strength of this study is the large sample size and a wide range of age groups and the use of longitudinal data in the Raine Study to compare with cross-sectional observations. A limitation of the present study is that the studies were conducted over a long time period between 2000 and 2019 and this could introduce some of the generational differences in the AL data that may be related to generational changes in height, even though prevalence of refractive error was relatively stable during this period in Australia.[8,51,52] Because of the long duration over which these studies were conducted, it is possible that Australians born in earlier decades may have, on average, shorter ALs than Australians born later across all ages causing AL increase with age to be underestimated. In addition, the population examined in these studies were mostly not from the urban centers of Australia, which could have also influenced the results. Another limitation is having an unequal number of samples across different age groups. We did not have additional information on the myopes, such as the age of onset of myopia and if the individuals were receiving any treatment for myopia at the time of examination, which might have influenced the AL measurements in younger-aged participants. However, it is unlikely that the individuals would be undergoing any myopia control treatment as it was not common at the time of eye examination for all cohorts. Finally, height information was available only from the Raine Study for adjusting as a co-variable.

Conclusions

Our cross-sectional data suggests that there is a minimal increase in AL in myopic eyes after the age of 18 years. Myopes have longer AL that increases more rapidly in childhood and slightly in early adulthood. Women have shorter AL than men of the same age group. The Raine Study longitudinal data revealed a greater progression in AL than earlier studies. Further studies of longitudinal changes in AL covering a large age range are required to guide myopia interventions.

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