Original Article

An Ecologic Study of Trends in the Prevalence of Myopia in Chinese Adults in Singapore Born from the 1920s to 1980s

Sonoko Sensaki, [1]*MD, MPH*, Charumathi Sabanayagam, [1,2,3]*MD, MPH, PhD*, Pavan K Verkicharla, [1]*BS (Optom), PhD*, Adeola Awodele,[4]*MD, MSc*, Kok Hian Tan,[5]*MBBS, MMed (O&G), FRCOG*, Audrey Chia, [1]*MBBS, FRANZCO, PhD*, Seang Mei Saw, [1,2,6]*MBBS, MPH, PhD*

Abstract

Introduction: This study aimed to investigate secular trends in the prevalence of myopia over 6 decades (from the 1920s to 1980s) in Chinese adults in Singapore. Materials and Methods: Parental myopia prevalence was estimated using a parent-completed questionnaire in paediatric cohorts that included: 1) The Singapore Cohort Of Risk factors for Myopia (SCORM), 2) The Strabismus, Amblyopia and Refractive Error in Singaporean Children (STARS), and 3) The Growing Up in Singapore Towards healthy Outcomes (GUSTO). Published estimates for myopia prevalence from 5 adult studies in Singapore were reviewed. Secular trends in the prevalence of myopia were correlated with changes in the education system. Results: The prevalence of parental myopia in SCORM (n = 2943), STARS (n = 4938), and GUSTO (n = 1072) was 47.8%, 53.4%, and 73.4%, respectively; corresponding calendar years these parents might have started schooling were 1966, 1973, and 1983 (born in 1960, 1967, and 1977), respectively. Mean age of parents was 41.3, 40.1, and 33.4 years, respectively. Prevalence of myopia in adult studies in persons who started elementary school in 1928, 1934, 1938, 1939, 1942, 1948, 1952, 1958, 1962, 1972, 1982, and 1995 were 36.4%, 39.7%, 30.0%, 31.5%, 33.0%, 26.4%, 32.5%, 48.7%, 39.4%, 52.0%, 82.2%, and 85.9%, respectively. Conclusion: During the past few decades, the prevalence of myopia increased rapidly, especially in persons who started elementary school after the 1980s (born after 1970). The education system was expanded after Singapore's independence in 1965, and the new education system was introduced in 1978. These changes, together with increasing intensive schooling, may have contributed to the increase in myopia prevalence.

Ann Acad Med Singapore 2017;46:229-36

Key words: Education, Refractive error, Secular trend

Introduction

Myopia is a significant public health problem. The prevalence of myopia is increasing substantially worldwide, particularly in east and southeast Asian urban areas,[1] where 80% to 90% of school leavers have myopia and 10% to 20% have high myopia.[2,3] This is of concern because myopia is associated with ocular complications leading to substantial visual loss.[4-6] In addition, the economic burden of myopia is also high, with the total estimated costs towards annual visits and optical purchases for myopia (excluding presbyopic lenses and sunglasses) of approximately SGD 959 (USD 755) million per year in Singapore.[7] Although myopiogenesis is known to interplay between genetic and/or environmental factors with the debated "nature versus nurture" effect, the steep increase in prevalence in the last few decades could possibly indicate a strong influence of the environment on myopia development.[2-5]

Previous studies have investigated trends in myopia prevalence and it is evident that the epidemic of myopia in several countries has gradually increased over

[1]Singapore Eye Research Institute and Singapore National Eye Centre, Singapore
[2]Centre for Quantitative Medicine, Duke-NUS Medical School, Singapore, Singapore
[3]Department of Ophthalmology, Yong Loo Lin School of Medicine, National University of Singapore and National University Health System, Singapore
[4]School of Medicine, Duke University, United States
[5]Department of Maternal Fetal Medicine, KK women's and Children's Hospital, Singapore
[6]Saw Swee Hock School of Public Health, National University of Singapore, Singapore
Address for Correspondence: Prof Saw Seang Mei, Myopia Research Group, Singapore Eye Research Institute, The Academia, 20 College Road, Discovery Tower Level 6, Singapore 169856.
Email: seang_mei_saw@nuhs.edu.sg

generations.[8-12] Cross-sectional surveys (National Health and Nutrition Examination Survey [NHANES]) conducted between 1971 to 1972 and 1999 to 2004 on the United States' population have shown significantly higher prevalence of myopia in persons aged 12 to 54 years in the latter cohort (41.6%) than the earlier one (25%).[8] An Israeli study reported an increase in the prevalence of myopia from 20.3% in 1990 to 28.3% in 2002 among candidates for security service aged 16 to 22 years.[9] In Singapore, serial surveys involving military conscripts showed an increasing trend in myopia prevalence in young adults aged 16 to 25 years, from 26% in 1974 to 1984, 44% in 1987 to 1991, 77% in 1996 to 1997, and 81% in 2009 to 2010, respectively.[3,10-12] However, they were limited by reporting changes over shorter periods of 10 to 30 years or including selective populations such as military conscripts.

We aimed to investigate the secular trends in myopia prevalence in Chinese adults using individual-level questionnaire data of parents from 3 paediatric cohorts,[13-18] and published estimates from 5 adult studies in Singapore.

Materials and Methods

Study Populations

Paediatric Cohorts

We assessed the prevalence of myopia in parents (born in 1959 to 1975) of children from 3 paediatric cohorts: the Singapore Cohort Of Risk factors for Myopia (SCORM), the Strabismus, Amblyopia and Refractive Error in Singaporean Children (STARS), and the Growing Up in Singapore Towards healthy Outcomes (GUSTO). SCORM is the first myopia cohort study in Asia involving 1979 children aged 7 to 9 years who were recruited from 3 schools in Singapore during the years 1999 to 2001 and were followed up annually until 2006.[13,14] STARS is a population-based study of 3009 children aged 6 to 72 months conducted by door-to-door recruitment between 2006 and 2008.[15,16] GUSTO is a mother-offspring cohort of 1176 babies who were recruited at 2 major public maternity units between 2009 and 2010, and are followed up to the present.[17,18] The refractive state (myope/emmetrope) of parents was determined based on a self-reported questionnaire by asking, "Is your child's mother/father myopic?" with "yes/no" in SCORM, "history of wearing glasses or contact lens for short-sighted" in STARS, and "current spectacles wear/contact lens" for distance vision with "yes/no" answer (spectacle prescription was also checked wherever possible) in GUSTO. The refraction data was available on 2943 parents (1479 fathers and 1464 mothers) in SCORM, 4938 (2469 fathers and 2469 mothers) in STARS and 1074 (535 fathers and 539 mothers) in GUSTO, all of Chinese ethnicity, whose mean year in which elementary school began were 1966, 1973 and 1983 (born in 1960, 1967, and 1975), respectively.

Adult Studies

We reviewed published estimates from 5 adult studies in Singapore with myopia data: the Tanjong Pagar Study (TPS, 1997-1998),[19] the Singapore Longitudinal Aging Study (SLAS, 2003-2011),[20] the Singapore Chinese Eye Study (SCES, 2009-2011),[21] and 2 military conscripts surveys (1996-1997; 2009-2010).[10] Myopia was defined as a spherical equivalent of at least -0.5 diopters by non-cycloplegic auto-refraction. Details of these studies are presented in Table 1.

Table 1. Evidence-based Survey of Myopia Prevalence in Chinese Adult Cohorts in Singapore

Author	Study	Year	Age at Recruitment (Years)	Birth Year	n (Men/Women)	Myopia Definition
Wong et al (2000)*	TPS	1997 – 1998	40 – 81	1922 – 1952	1113 (500/613)	Auto-refraction SE <-0.5D
Tan et al (2011)†	SLAS	2003 – 2011	55 – 85	1918 – 1948	1835 (670/1165)	Auto-refraction SE <-0.5D
Pan et al (2013)‡	SCES	2009 – 2011	40 – 80	1936 – 1966	3251 (1605/1646)	Auto-refraction SE <-0.5D
Koh et al (2014)§	Military conscripts	1996 – 1997	16 – 25	1971 – 1981	12,370 (12370/0)	Auto-refraction SE <-0.5D
Koh et al (2014)§	Military conscripts	2009 – 2010	17 – 29	1981 – 1993	20,004 (20004/0)	Auto-refraction SE <-0.5D

SCES: Singapore Chinese Eye Study; SE: Spherical equivalent; SLAS: Singapore Longitudinal Ageing Study; TPS: Tanjong Pagar Study

*Wong TY, Foster PJ, Hee J, Ng TP, Tielsch JM, Chew SJ, et al. Prevalence and risk factors for refractive errors in adult Chinese in Singapore. Invest Ophthalmol Vis Sci 2000;41:2486-94.

†Tan CS, Chan YH, Wong TY, Gazzard G, Niti M, Ng TP, et al. Prevalence and risk factors for refractive errors and ocular biometry parameters in an elderly Asian population: the Singapore Longitudinal Aging Study (SLAS). Eye 2011;25:1294-301.

‡Pan CW, Zheng YF, Anuar AR, Chew M, Gazzard G, Aung T, et al. Prevalence of refractive errors in a multiethnic Asian population: the Singapore epidemiology of eye disease study. Invest. Ophthalmol Vis Sci 2013;54:2590-8.

§Koh V, Yang A, Saw SM, Chan YH, Lin ST, Tan MM, 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.

Table 2. Secular Trend of Self-Reported Myopia Prevalence in Chinese Adults in Singapore

	SCORM*	STARS†	GUSTO‡
Fathers			
Year started in elementary school (mean)	1965	1974	1981
No. of years since Singapore's independence	0	+9§	+16§
Year of birth (mean)	1959	1968	1975
Age (mean)	43.0	37.7	34.8
Total sample size (n)	1479	2469	535
Total prevalence (%)	40.8	48.6	73.4
Mothers			
Year started in elementary school (mean)			
No. of years since Singapore's independence	+3§	+6§	+20§
Year of birth (mean)	1962	1965	1979
Age (mean)	39.6	42.4	32.1
Total sample size (n)	1464	2469	537
Total prevalence (%)	54.8	58.2	75.0
Overall			
Year started in elementary school (mean)			
No. of years since independence	+1§	+8§	+18§
Year of birth (mean)	1960	1967	1977
Age (mean)	41.3	40.1	33.4
Total sample size (n)	2943	4938	1074
Total prevalence (%)	47.8	53.4	75.3

SCORM: Singapore Cohort of Risk factors for Myopia; STARS: Strabismus, Amblyopia and Refractive Error in Singaporean Children; GUSTO: Growing Up in Singapore Towards Healthy Outcomes

*Saw SM, Tong L, Chua WH, Chia KS, Koh D, Tan DT, et al. Incidence and progression of myopia in Singaporean school children. Invest. Ophthalmol Vis Sci 2005;46:51-7. Samarawickrama C, Mitchell P, Tong L, Gazzard G, Lim L, Wong TY, et al. Myopia-related optic disc and retinal changes in adolescent children from singapore. Ophthalmology 2011;118:2050-7.

†Dirani M, Chan YH, Gazzard G, Hornbeak DM, Leo SW, Selvaraj P, et al. Prevalence of refractive error in Singaporean Chinese children: the strabismus, amblyopia, and refractive error in young Singaporean Children (STARS) study. Invest. Ophthalmol Vis Sci 2010;51:1348-55. Chia A, Lin X, Dirani M, Gazzard G, Ramamurthy D, Quah BL, et al. Risk factors for strabismus and amblyopia in young Singapore Chinese children. Ophthalmic Epidemiol 2013;20:138-47.

‡Soh SE, Lee SS, Hoon SW, Tan MY, Goh A, Lee BW, et al. The methodology of the GUSTO cohort study: a novel approach in studying pediatric allergy. Asian Pac J Allergy 2012;2:144-8. Soh SE, Tint MT, Gluckman PD, Godfrey KM, Rifkin-Graboi A, Chan YH, et al. Cohort profile: Growing Up in Singapore Towards healthy Outcomes (GUSTO) birth cohort study. Int J Epidemiol 2014;43:1401-9.

§'+' indicates years after independence.

Statistical Analyses

The prevalence of myopia was calculated separately in males and females. Based on the assumption that people start their elementary school education from 6 years of age in Singapore (on average), the year parents commenced elementary school was calculated using their year of birth. The prevalence of myopia according to the year participants started elementary school was calculated and the statistical significance of the trend was examined using the chi-square test. Statistical analysis was conducted using Stata version 14 (StataCorp LP, TX, USA).

Results

The prevalence of parental myopia in SCORM, STARS, and GUSTO and other related details are shown in Table 2. The prevalence of parental myopia peaked over time with estimates of 47.8%, 53.4% and 75.3% in parents whose elementary school began in year 1966 in SCORM, 1973 in STARS, and 1983 in GUSTO (born in 1960, 1967, and 1975), respectively. The mean age of these parents at the time of data collection was 41.3 ± 5.3, 40.1 ± 3.2, and 33.4 ± 5.5 years. The prevalence of myopia in parents who started/attended school before the 1980s was significantly lower (47.8% in 1966 in SCORM, 53.4% in 1973 in STARS), compared to those who attended school later (75.3% in 1983 in GUSTO).

Table 3 shows an evidence-based survey of myopia prevalence in Chinese adults who were born during the 1920s to 1990s. The myopia prevalence of Chinese adults (aged 40 to 81 years) from the TPS whose elementary school began from the year 1928 to 1958 (born in 1922 to 1952) were 36.4% in those who began school in year 1928, 30.0% in 1938, 26.4% in 1948, 48.7% in 1958. The myopia prevalence in Chinese adults (aged 65 to 80 years) from SLAS were 39.4% in those who began elementary school in year 1934 (born in 1928) and 31.5% in year 1939 (born in 1933). The prevalence of myopia in Chinese adults (aged 40 to 80 years) from the SCES whose elementary school began from the years 1942 to 1972 (born in 1936 to 1966) were 33% in those who began school in year 1942, 32.5% in 1946, 39.4% in 1962, and 52% in 1972, showing a gradual increase over time. Their mean age at the time of data collection was 75.2, 64.4, 54.7, and 47.6 years, respectively. The prevalence of myopia in women was, 30.6% in those who began school in year 1942 and 28.8% in 1952; till 1962, prevalence of myopia in females was lower than men (34.7% in 1942 and 35.9% in 1962). After 1962, prevalence of myopia in females was 40.8% in 1962 and 56.3% in 1972, higher than the prevalence in men with 37.6% in those who began school in year 1962 and 47.5% in 1972 in SCES. Prevalence of myopia in Chinese teens and enrolled young adult military conscripts adults (aged

Table 3. Evidence-based Survey of Myopia‖ Prevalence[‖] in Chinese Adults in Singapore

Study	TPS[*]	SLAS[†]	TPS[*]	SLAS[†]	SCES[‡]	TPS[*]	SCES[‡]	TPS[*]	SCES[‡]	SCES[‡]	Military Conscripts Study[§]	
Men												
Year started in elementary school (mean)	1928	-	1938	-	1942	1948	1952	1958	1962	1972	1982	1995
No. of years since independence[¶]	-37	-	-27	-	-23	-17	-13	-7	-3	+7	+17	+30
Birth year (mean)	1922	-	1932	-	1936	1942	1946	1952	1956	1966	1976	1989
Age at recruitment (range/mean)	70-	-	60 – 69	-	70- (74.9)	50 – 59	60 – 69 (64.3)	40 – 49	50 – 59 (54.8)	40 – 49 (47.6)	16 – 25 (19.5)	17 – 29 (19.8)
Total sample size (n)	104	-	157	-	310	115	454	124	495	346	12,370	20,004
Total prevalence (%)	31.7	-	29.2	-	34.7	25.2	35.9	45.2	37.6	47.5	82.2	85.9
Women												
Year started in elementary school (mean)	1928	-	1938	-	1942	1948	1952	1958	1962	1972	-	-
No. of years since independence[¶]	-37	-	-27	-	-23	-27	-13	-7	-3	+7	-	-
Birth year (mean)	1922	-	1932	-	1936	1942	1946	1952	1956	1966	-	-
Age (range/mean)	70-	-	60 – 69	-	70- (75.6)	60 – 69	60 – 69 (64.5)	40 – 49	50 – 59 (54.7)	40 – 49 (47.6)	-	-
Total sample size (n)	124	-	150	-	279	188	409	151	598	360	-	-
Total prevalence (%)	40.3	-	30.0	-	30.6	27.1	28.8	51.7	40.8	56.3	-	-
Overall												
Year started in elementary school (mean)	1928	1934	1938	1939	1942	1948	1952	1958	1962	1972	-	-
No. of years since independence[¶]	-37	-31	-27	-26	-23	-27	-13	-7	-3	+7	-	-
Birth year (mean)	1922	1928	1932	1933	1936	1942	1946	1952	1956	1966	-	-
Age (range/mean)	70-	75-	60 – 69	65 – 75	70- (75.2)	50 – 59	60 – 69 (64.4)	40 – 49	50 – 59 (54.7)	40 – 9 (47.6)	-	-
Total sample size (n)	228	-	307	-	589	303	863	275	1093	706	-	-
Total prevalence (%)	36.4	39.7	30.0	31.5	33.0	26.4	32.5	48.7	39.4	52.0	-	-

SCES: Singapore Chinese Eye Study; SLAS: Singapore Longitudinal Aging Study; TPS: Tanjong Pagar Study

[*]Wong TY, Foster PJ, Hee J, Ng TP, Tielsch JM, Chew SJ, et al. Prevalence and risk factors for refractive errors in adult Chinese in Singapore. Invest. Ophthalmol Vis Sci 2000;41:2486-94.

[†]Tan CS, Chan YH, Wong TY, Gazzard G, Niti M, Ng TP, et al. Prevalence and risk factors for refractive errors and ocular biometry parameters in an elderly Asian population: the Singapore Longitudinal Aging Study (SLAS). Eye 2011;25:1294-301.

[‡]Pan CW, Zheng YF, Anuar AR, Chew M, Gazzard G, Aung T, et al. Prevalence of refractive errors in a multiethnic Asian population: the Singapore epidemiology of eye disease study. Invest. Ophthalmol Vis Sci 2013;54:2590-8.

[§]Koh V, Yang A, Saw SM, Chan YH, Lin ST, Tan MM, 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.

[‖]Methods of diagnosis of myopia: non-cycloplegic auto-refraction (spherical equivalent <-0.5 D).

[¶]'-'indicates years before independence and '+' indicates years after independence.

16 to 29 years) whose elementary school began in 1982 to1995 (born in 1976 to 1989) were over 80%, roughly twice as high as participants who started schooling before the 1980s in SCES and TPS. The prevalence of myopia further increased slightly from 82.2% (n = 12,370) in 1982 to 85.9% in 1995 (n = 20,004). The mean age of the participants at the time of data collection was 19.5 ± 1.4 years and 19.8 ± 1.2 years, respectively.

Figure 1 shows the change in myopia prevalence in Chinese male adults as a function of "mean year elementary school begins" from 5 population-based cohorts (TPS, SCES, SCORM, STARS, and GUSTO) and military conscripts. Myopia prevalence data from females was excluded from the figure for better meaningful comparisons with other studies that has only men (like military conscripts). The graph indicates a continuous upward trend over the whole range of years from the 1940s to the 1990s. It shows a gradual increase in myopia prevalence from 30% to 50% during the first 30 years, then an exponential rise in individuals who started schooling after the 1980s (born after 1970), jumping to a high prevalence of over 80% (P for trend <0.001). The major changes in the education system in Singapore are illustrated chronologically to explore its relationship with the myopia prevalence.[22] The education system was expanded after independence in 1965, and enhanced its competitiveness rapidly after the introduction of the New Education System (NES) in 1978.

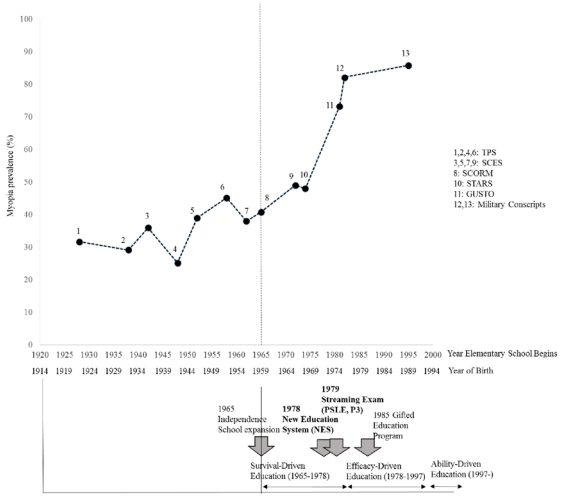

Fig. 1. Myopia prevalence as a function of year elementary school begins for Chinese males from SCES, SCORM, STARS, GUSTO and military conscripts, and education system changes in Singapore (statistical significance of trend; X^2 = 2528.672, P <0.001). Survival-driven education (1965-1978): Focus on quantity, expanding schools and aim of higher enrolment rate into educational institutions. Efficacy-driven education (1978-1997): Focus on quality efficacy, streaming students into different levels of classes for their ability by examination (New Education System). Ability-driven education (1997-ongoing): Focus on students' ability, expanding variations and flexible choices according to students' differences in ability.

Discussion

This ecologic study shows that prevalence of myopia may be increasing in Singapore in persons who started schooling from 1928 to 1995 (year of birth 1922 to 1989), with a secular upward trend and a rapid increase in persons who began schooling after the 1980s (year of birth after 1970). Ecologic studies may provide interesting observational trend data of both exposure and disease. This ecologic study may confirm findings from prior cohort studies of the environmental risk factors for myopia and the effect of the environment on secular trends.

Similar to this study's result, an upward secular trend has been seen in other countries. In the United States' national survey NHANES, myopia prevalence in persons aged 12 to 54 years was significantly higher in 1999 to 2004 (41.6%, n = 9609) than in 1971 to 1972 (25%, n = 5282).[8] In the Israeli study that examined 919,929 security service candidates aged 16 to 22 years, myopia prevalence rose from 20.3% in 1990 to 28.3% in 2002.[9] In other observational studies, the rapid increase of myopia prevalence in the 20th century was first noted in Eskimos in North America as the population moved into settlements. While no cases of myopia were recorded in 1947, 4.7% of adults and 16.6% of children had myopia in 1962 in Eskimos.[23] In Singapore, all the major races (Chinese, Indians, and Malays) experienced dramatic growth in myopia prevalence roughly in parallel with approximately 50% to 85%, 30% to 75%, 25% to 70%, respectively, between 1987 and 2010.[24,25] In the Chinese population, a Taiwanese study examined 300 randomly selected students for each age group from 7 to 18 years between 1983 and 2000, and found the dramatic upward trend in myopia prevalence, from 5.8% to 21% among 7 year olds, from 36.7% to 61% among 12 year olds, and from 64.2% to 81% among 15 year olds.[2] The Beijing Childhood Eye Study examined 15,066 children aged from 7 to 18 years in 2008 and found that prevalence of myopia of <-1.00 D increased from 9.7% in 7 year olds to 74.2% in 17-18 year olds. The latter figure was already higher than the prevalence in elderly Beijing Eye study population 10 years before, which indicates an ongoing myopic shift in the young generation and prognosticates an increase in myopia prevalence in the future adult population in mainland China.[26] In other meta-analysis, the study including 50 population-based studies with 215,672 subjects aged 0 to 96 years reporting the prevalence of myopia from 16 Asian countries found that the upward trend for both age and year of birth, 28.2% with 60 to 69 years old to 47.3% with 20 to 29 years old, 23% with people born in 1960 to 1969 to 39.9% born in 1920 to 1929.[27] The meta-analysis including 145 studies covering 2.1 million people from all over the world estimated significant increase in prevalence globally, from 22.9% in 2000 to 49.8% in 2050.[28]

Worldwide myopia prevalence is increasing, which should be related to environmental factors. The environmental factors for myopia are near-work and lack of outdoor time.[29-32] In adult studies of myopia, it is difficult to obtain near-work activity prior to the onset of childhood myopia and often the final level of education attained is the best surrogate.[33] The increased myopia prevalence in the 20th century might be associated with increasing intensive education, mediated by more near-work and lifestyle changes with reduced outdoor time.[29-32]

Several studies investigated increasing myopia prevalence and the relationship between myopia prevalence and education systems. For instance, the Chinese study examined 8267 children aged 3 to 10 in 2013 in Shanghai, and found that myopia prevalence increased from 1.78% in 3-year-olds to 52.2% in 10-year-olds, which was statistically associated with attending elite "high-level" school.[34] The Korean National Health and Nutrition Examination Survey 2008-2011 examined 23,392 people aged 20+ years by auto-refraction, and found that myopia prevalence in the younger generation (78.9% in 20 to 29 years old, 60.7% in 40 to 49 years old) was much higher than the older generation (16.1% in 60 to 69 years old), which was associated with an increased education level. The change may be related to the rapid economic development of Korea, and with the accompanying transformation in education, high level of education (high school or university graduate) increased sharply from 16.2% to 96.9% over 40 years.[35] The Tajimi study that examined a random sample of 3021 Japanese aged 40 years or older found that the prevalence of myopia decreased with increasing age from 70.3% in 40 years to 13.5% in 80 years, and suggested that the decrease may reflect a rapid economic development and education expansion after the end of the Second World War in 1945.[36]

In Singapore, between 1819 and 1963, the education system was modelled after the British system. Immediately following independence in 1965, major reforms—the so-called "Survival-Driven Education"—focusing on quantity of education were implemented. The NES was introduced in 1978 to allow pupils to study at their pace, more suited for their ability. The Primary School Leaving Examination at 12 years and primary streaming exam for Primary 3 students, were used to channel students into different level of classes, and had begun in 1978 and 1979, respectively. In addition, in 1984, the 'Gifted Education Programme' commenced, in which very highly performing students were channelled into a special programme with extra enrichment classes. A large proportion of students are engaged in extra academic lessons called "tuition". The change in the education system with more intensive schooling since 1978, may have led to the increasing prevalence of myopia in Singapore.[21]

The strength of the current study is that the results presented here are based on population-based data with large sample sizes and reasonable response rates (SCORM, STARS and GUSTO),[13-18] which include over 7 decades of data of persons who entered schools in different calendar years. All participants were of the same race (Chinese) which is advantageous in avoiding ethnic variation.

There were also some limitations. The most important limitation is that this is an ecologic study with only observation of myopia over time and changes in the schooling system over time.

In addition, as this study is an ecological study, ecological fallacy may be considered. The correlation of exposure and disease was shown only at the group level but not at the individual level. Causality cannot be inferred. Education and myopia development should have various confounders. In addition to changes in education system, many other environmental factors such as changes in socioeconomic status, changes in reduced outdoor life style, increased near-work with electronic gadgets such as handphones and computers, or increased crowded urban spaces may also have contributed to this increase.

Second, the heterogeneity between the studies should be noted. The method of myopia assessment is different between studies in that it is based on self-report in STARS, SCORM and GUSTO, and based on non-cycloplegic auto-refraction in the others. Self-reporting may have biased the results as participants may be mistaken or misremember the information. According to the validity of self-reporting myopia prevalence in previous studies, accuracy is different between the asking methods. The direct asking method of "Are you myopic?" (like SCORM) showed the sensitivity and specificity with 0.54 and 0.83, while the indirect method using a series of questions on the use of eyeglasses and age at first dispensing (like STARS and GUSTO) showed with 0.76 and 0.74.[37] Examining prescribed distance glasses like GUSTO showed a good sensitivity (80%) and specificity (89%).[38] The Singapore Malay Eye Study (population-based, cross-sectional study), examined 2912 adults aged 40 to 80 years, and found that people with uncorrected myopia who do not wear spectacles was 4.5%.[39] We project that the rates of self-reported myopia in our study may be underestimated by approximately 4% and thus the true myopia rates are slightly higher. Parents who participated in the study might be more concerned about myopia, more affluent, or closer to the clinical sites, which may also have introduced a selection bias. The enrolment strategy of children's study, such as 3 school-based (2 ordinary schools from eastern and 1 from northern provinces) design for SCORM, 2 hospital-based (maternity units) for GUSTO, and door-to-door recruitment from southwest provinces for STARS, may not have provided a true representation of the entire population and may have led to either an over- or

underestimation of prevalence.

Age is a well known factor affecting the prevalence of refractive errors. While parental age of paediatric cohorts were approximately the same, age in the adult cohorts varied greatly from the teens in military conscripts to 40 to 80 years in SCES and TPS cohorts. Since myopia may progress till 25 years, some of the young military conscripts may still become myopic after 16 years. Nuclear cataracts which is age-related may cause index myopia in later life, as increasing nuclear sclerosis of the lens with age leads to a myopic shift in refractive status.[40] Thus, myopia prevalence in these conscripts may even be higher than the published estimates, compared with older adults in SCES and TPS. This may be especially so given the exponential rise in myopia prevalence in persons who began schooling after the 1980s (born after the 1970s).

Conclusion

This ecologic study showed a secular upward trend in myopia prevalence in Chinese adults who started elementary school from 1928 to 1995 (born in 1922-1989), in particular, an exponential rise in prevalence in persons who started elementary school after the 1980s (born after 1970), which may be related to increasing education after independence and specifically to the enhanced competition introduced by NES in 1978. Further population-based cohort studies will be required to identify the association at the individual level since this ecological study shows the association only at a group level. From the perspective of public health policies to prevent myopia, children should not be given excessive schooling demands. Policymakers, parents, and education experts should be aware of the associations of intensive schooling with myopia.

Acknowledgements

*The study was supported by a grant, Singapore-NMRC/TCR/004-NUS/2008, NMRC/TCR/012-NUHS/2014, and additional funding by the Singapore Institute for Clinical Sciences, Agency for Science Technology and Research (A*STAR) for GUSTO, NMRC/SERI/MG/97-04/0005 for SCORM, NMRC/1009 /2005 for STARS.*

The authors would like to thank the GUSTO study group: Allan Sheppard, Amutha Chinnadurai, Anne Eng Neo Goh, Anne Rifkin-Graboi, Anqi Qiu, Arijit Biswas, Bee Wah Lee, Birit FP Broekman, Boon Long Quah, Borys Shuter, Chai Kiat Chng, Cheryl Ngo, Choon Looi Bong, Christiani Jeyakumar Henry, Cornelia Yin Ing Chee, Yam Thiam Daniel Goh, Doris Fok, Fabian Yap, George Seow Heong Yeo, Helen Chen, Hugo PS van Bever, Iliana Magiati, Inez Bik Yun Wong, Ivy Yee-Man Lau, Jeevesh Kapur, Jenny L Richmond, Jerry Kok Yen Chan, Joanna D Holbrook, Joshua J Gooley, Keith M Godfrey, Kenneth Kwek, Kok Hian Tan, Krishnamoorthy Niduvaje, Leher Singh, Lin Lin Su, Lourdes Mary Daniel, Lynette Pei-Chi Shek, Marielle V Fortier, Mark Hanson, Mary Foong-Fong Chong, Mary Rauff, Mei Chien Chua, Michael Meaney, Mya Thway Tint, Neerja Karnani, Ngee Lek, Oon Hoe Teoh, PC Wong, Peter D Gluckman, Pratibha Agarwal, Rob M van Dam, Salome A Rebello, Seang-Mei Saw, Shang Chee Chong, Shirong Cai, Shu-E Soh, Sok Bee Lim, Chin-Ying Stephen Hsu, Victor Samuel Rajadurai, Walter Stunkel, Wee Meng Han, Wei Wei Pang, Yap-Seng Chong, Yin Bun Cheung, Yiong Huak Chan and Yung Seng Lee.

REFERENCES

1. Pan CW,Ramamurthy D,Saw SM. Worldwide prevalence and risk factors for myopia. Ophthalmic Physiol Opt 2012;32:3-16.
2. Lin LL, Shih YF, Hsiao CK, Chen CJ. Prevalence of myopia in Taiwanese schoolchildren: 1983 to 2000. Ann Acad Med Singapore 2004;33:27-33.
3. Wu HM, Seet B, Yap EP, Saw SM, Lim TH, Chia KS. Does education explain ethnic differences in myopia prevalence? A population-based study of young adult males in Singapore. Optom Vis Sci 2001;78:234-9.
4. Charman N. Myopia: its prevalence, origins and control. Ophthalmic Physiol Opt 2011;31:3-6.
5. Saw SM, Gazzard G, Shih-Yen EC, Chua WH. Myopia and associated pathological complications. Ophthalmic Physiol Opt 2005;25:381-91.
6. Bourne RR, Stevens GA, White RA, Smith JL, Flaxman SR, Price H, et al. Causes of vision loss worldwide, 1990-2010: a systematic analysis. Lancet Glob Health 2013;1:e339-49.
7. Lim MC, Gazzard G, Sim EL, Tong L, Saw SM. Direct costs of myopia in Singapore. Eye 2009;23:1086-9.
8. Vitale S, Sperduto RD, Ferris FL, 3rd. Increased prevalence of myopia in the United States between 1971-1972 and 1999-2004. Arch Opthalmol 2009;127:1632-9.
9. Bar Dayan Y, Levin A, Morad Y, Grotto I, Ben-David R, Goldberg A, 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. Koh V, Yang A, Saw SM, Chan YH, Lin ST, Tan MM, 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.
11. Tay MT, Au Eong KG, Ng CY, Lim MK. Myopia and educational attainment in 421,116 young Singaporean males. Ann Acad Med Singapore 1992;21:785-91.
12. Au Eong KG, Tay TH, Lim MK. Race, culture and Myopia in 110,236 young Singaporean males. SMJ 1993;34:29-32.
13. Saw SM, Tong L, Chua WH, Chia KS, Koh D, Tan DT, et al. Incidence and progression of myopia in Singaporean school children. Invest Ophthalmol Vis Sci 2005;46:51-7.
14. Samarawickrama C, Mitchell P, Tong L, Gazzard G, Lim L, Wong TY, et al. Myopia-related optic disc and retinal changes in adolescent children from Singapore. Ophthalmology 2011;118:2050-7.
15. Dirani M, Chan YH, Gazzard G, Hornbeak DM, Leo SW, Selvaraj P, et al. Prevalence of refractive error in Singaporean Chinese children: the strabismus, amblyopia, and refractive error in young Singaporean Children (STARS) study. Invest Ophthalmol Vis Sci 2010;51:1348-55.
16. Chia A, Lin X, Dirani M, Gazzard G, Ramamurthy D, Quah BL, et al. Risk factors for strabismus and amblyopia in young Singapore Chinese children. Ophthalmic Epidemiol 2013;20:138-47.
17. Soh SE, Lee SS, Hoon SW, Tan MY, Goh A, Lee BW, et al. The methodology of the GUSTO cohort study: a novel approach in studying pediatric allergy. Asian Pac J Allergy 2012;2:144-8.

18. Soh SE, Tint MT, Gluckman PD, Godfrey KM, Rifkin-Graboi A, Chan YH, et al. Cohort profile: Growing Up in Singapore Towards healthy Outcomes (GUSTO) birth cohort study. Int J Epidemiol 2014;43:1401-9.
19. Wong TY, Foster PJ, Hee J, Ng TP, Tielsch JM, Chew SJ, et al. Prevalence and risk factors for refractive errors in adult Chinese in Singapore. Invest. Ophthalmol Vis Sci 2000;41:2486-94.
20. Tan CS, Chan YH, Wong TY, Gazzard G, Niti M, Ng TP, et al. Prevalence and risk factors for refractive errors and ocular biometry parameters in an elderly Asian population: the Singapore Longitudinal Aging Study (SLAS). Eye 2011;25:1294-301.
21. Pan CW, Zheng YF, Anuar AR, Chew M, Gazzard G, Aung T, et al. Prevalence of refractive errors in a multiethnic Asian population: the Singapore epidemiology of eye disease study. Invest. Ophthalmol Vis Sci 2013;54:2590-8.
22. Goh CB, Gopinathan S. Education in Singapore: Development since 1965. In: B Fredriksen & JP Tan, editors. An African Exploration of the East Asian Education. Washington, DC: The World Bank; 2008. p 80-108.
23. Johnson GJ. Myopia in arctic regions. A survey. Acta Ophthalmol Suppl 1988;185:13-8.
24. Pan CW, Wong TY, Lavanya R, Wu RY, Zheng YF, Lin XY, et al. Prevalence and risk factors for refractive errors in Indians: the Singapore Indian Eye Study (SINDI). Invest Ophthalmol Vis Sci 2011;52:3166-73.
25. Saw SM, Chan YH, Wong WL, Shankar A, Sandar M, Aung T, et al. Prevalence and risk factors for refractive errors in the Singapore Malay Eye Survey. Ophthalmology 2008;115:1713-9.
26. Ma Y, Qu X, Zhu X, Xu X, Zhu J, Sankaridurg P, et al. Age-Specific Prevalence of Visual Impairment and Refractive Error in Children Aged 3-10 Years in Shanghai, China. Invest Ophthalmol Vis Sci 2016;57:6188-96.
27. Pan CW, Dirani M, Cheng CY, Wong TY, Saw SM. The age-specific prevalence of myopia in Asia: a meta-analysis. Optom Vis Sci 2015;92:258-66.
28. Holden BA, Fricke TR, Wilson DA, Jong M, Naidoo KS, Sankaridurg P, et al. Global Prevalence of Myopia and High Myopia and Temporal Trends from 2000 through 2050. Ophthalmology 2016;123:1036-42.
29. Rose KA, Morgan IG, Ip J, Kifley A, Huynh S, Smith W, et al. Outdoor activity reduces the prevalence of myopia in children. Ophthalmology 2008;115:1279-85.
30. 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.
31. Sherwin JC, Reacher MH, Keogh RH, Khawaja AP, Mackey DA, Foster PJ. The association between time spent outdoors and myopia in children and adolescents: a systematic review and meta-analysis. Ophthalmology 2012;119:2141-51.
32. Saw SM, Hong CY, Chia KS, Stone RA, Tan D. Nearwork and myopia in young children. Lancet 2001;357:390.
33. Williams KM, Bertelsen G, Cumberland P, Wolfram C, Verhoeven VJ, Anastasopoulos E, et al. Increasing Prevalence of Myopia in Europe and the Impact of Education. Ophthalmology 2015;122:1489-97.
34. You QS, Wu LJ, Duan JL, Luo YX, Liu LJ, Li X, et al. Prevalence of myopia in school children in greater Beijing: the Beijing Childhood Eye Study. Acta Ophthalmol 2014;92:e398-406.
35. Kim EC, Morgan IG, Kakizaki H, Kang S, Jee D. Prevalence and risk factors for refractive errors: Korean National Health and Nutrition Examination Survey 2008-2011. PloS One 2013;8:e80361.
36. Sawada A, Tomidokoro A, Araie M, Iwase A, Yamamoto T, Tajimi Study Group. Refractive errors in an elderly Japanese population: the Tajimi study. Ophthalmology 2008;115:363-70.e3.
37. Walline JJ, Zadnik K, Mutti DO. Validity of surveys reporting myopia, astigmatism, and presbyopia. Optom Vis Sci 1996;73:376-81.
38. Cumberland PM, Peckham CS, Rahi JS. Capturing myopia and hypermetropia 'phenotypes' without formal refraction. Eye 2008;22:939-43.
39. Lamoureux EL, Saw SM, Thumboo J, Wee HL, Aung T, Mitchell P, et al. The impact of corrected and uncorrected refractive error on visual functioning: the Singapore Malay Eye Study. Invest Ophthalmol Vis Sci 2009;50:2614-20.
40. Samarawickrama C, Wang JJ, Burlutsky G, Tan AG, Mitchell P. Nuclear cataract and myopic shift in refraction. Am J Ophthalmol 2007;144:457-9.