A LONGITUDINAL STUDY OF OCULAR BIOMETRY AND VISION-RELATED QUALITY OF LIFE IN SINGAPORE YOUNG ADULTS

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Thesis Summary

Myopia is a serious health problem that has reached epidemic levels in Asian cities such as Taiwan, South Korea, and Singapore. However, there is a lack of cross-sectional and longitudinal data on refractive error and ocular biometry in young adults, especially in Singapore. Despite the high prevalence of myopia in Singapore, vision-related quality of life (VRQOL) is also inadequately examined.

This longitudinal study sets out to examine the refraction, ocular biometry and VRQOL over a 24-month period. Participants were recruited from the student pool of a tertiary education institution. Subjective refraction, ocular biometry, and accommodative response measurements were performed for participants. The NEI-RQL-42 questionnaire and a bespoke questionnaire were completed by participants.

Out of 99 participants (age range 16 to 22 year) at the baseline visit, 86.8 % were myopic. The age of initial refractive correction was significantly associated with refractive error, while near work, sports activities, outdoor activities, accommodative responses, and primary school leaving examinations were not. Among the 88 participants who completed the 24 month visit, the percentage of myopes remained stable, with no increase in myopia. Ocular biometric parameters also remained stable, with only a non-clinically significant increase of 0.02mm in axial length.

Non-Myopes exhibited the highest VRQOL, while Mod/High-Myopes had the lowest VRQOL. Myopia and contact lens wear were found to be the main contributors towards poorer VRQOL. VRQOL remained stable over the 24 month period, with the exception that moderate and high myopes exhibited an improvement in VRQOL on their dependence of correction.

In conclusion, this study presented novel findings on stable refraction and ocular biometry in Singapore young adults over a 24 month period, which was contrary to previous findings on university students. In addition, VRQOL remained unchanged over a 24 month period, where myopia and contact lens wear were found to cause poorer VRQOL in participants.

Keywords: Myopia, refractive error, VRQOL, axial length, tertiary students

For Madeleine and Kyler

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List of Abbreviations

ACD	Anterior Chamber Depth
AEI	Accommodative Error Index
AL	Axial Length
AL/CR	Axial Length / Corneal Radius Ratio
ANOVA	Analysis of Variance
ASRC	Accommodative Stimulus Response Curve
AU REC	Aston University Research Ethics Committee
CL	Contact Lens
CLEERE	Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error Study
CLM-Wearers	Contact Lens Mixed-Wearers
COMET	Correction of Myopia Evaluation Trial
CR	Corneal Radius
CT	Corneal Thickness
GCE	General Certificate of Education
GPA	Grade Point Average
HGF	Hepatocyte Growth Factor
IOL	Intraocular Lens
IQ	Intelligent Quotient
LASIK	Laser Assisted Subepithelial In-Situ Keratomilieusis
LT	Lens Thickness
MSE	Mean Spherical Equivalent
NEI-RQL-42	National Eye Institute Refractive Error Quality of Life Instrument
NEI-VFQ	National Eye Institute Visual Function Questionnnaire
NP-IRB	Ngee Ann Polytechnic Institutional Review Board
NPOC	Ngee Ann Polytechnic Optometry Centre

OLCR	Optical Low-Coherence Reflectometry
OLSM	Orinda Longitudinal Study of Myopia
SCORM	Singapore Cohort of Study of the Risk Factors for Myopia
SE	Spherical Equivalent
SNP	Single Nucleotide Polymorphism
TV	Television
VCD	Vitreous Chamber Depth
VCM1	Vision Core Measurement 1 Instrument
VF-14	Vision Function 14 Instrument
VisQol	Vision and Quality of Life Instrument
VQOL	Vision Quality of Life Instrument
VRQOL	Vision-related Quality of Life

Chapter 1: Introduction

Refractive errors encompassing myopia, hyperopia, and astigmatism occur as a result of a defective refractive system where light rays do not precisely focus on the retina. Worldwide, it is estimated that there are more than 800 million people with refractive errors (Dunaway and Berger, 2015). In the United States alone, 30.4 million people suffer from myopia and 11.8 million people suffer from hyperopia. In Western Europe, 49.6 million people suffer from myopia and 21.6 million people suffer from hyperopia. Given the staggering prevalence of refractive errors, it is not surprising that uncorrected refractive error is the leading cause of preventable visual impairment (World Health Organisation, 2015). An estimated 153 million people suffer from vision impairment without access to proper refractive correction (Resnikoff et al., 2008).

Myopia is the most prevalent spherical refractive error, which was recently estimated to affect 28.3 % of the global population in 2010 (Holden et al., 2016), and is projected to increase to 49.8 % of the global population in 2050, affecting nearly 4.76 billion people. The prevalence of myopia was reported to be the highest in urban Asian cities such as Singapore and Taiwan (Saw, 2003), which increases economic burdens due to refractive correction and the medical treatment of its pathological complications (Lim et al., 2009; Seet et al., 2001; Vitale et al., 2006; Zheng et al., 2013). The prevalence and severity of myopia has been reported to be implicated by higher education (Tay et al., 1992; Wu et al., 2001), increased near work activities (Ip et al., 2008; Saw et al., 2002b), reduced outdoor activities (Rose et al., 2008a; Dirani et al., 2009), and genetics (Mutti et al., 2002; Morgan and Rose, 2009). While it is well established that myopia progression occurs from the age of six (Jones et al., 2005; Saw et al., 2005b; Wong et al., 2010), less is known about the changes in refraction and axial length in young adults after 16 years of age. Longitudinal studies in Norway, Turkey, Portugal and China had reported myopic progression in university students (Lin et al., 1996; Kinge and Midelfart, 1999; Onal et al., 2007; Jorge et al., 2007). However, there have been no longitudinal studies to investigate ocular biometric changes in young adults studying in higher education institutions in Singapore, where the prevalence of myopia reaches epidemic proportions (Pan et al., 2013b).

The survey of quality of life has become an important aspect of clinical subjective assessment of ocular pathologies that can drastically affect visual performance (Frost et al., 2001). Although uncorrected refractive error has been demonstrated to reduce visual function-related quality of life (Congdon et al., 2008; Lamoureux et al., 2009), there are insufficient reports to associate corrected myopia to vision-related quality of life (VRQOL) (Lamoureux and Wong, 2010). The vision core measure 1 (VCM1) questionnaire was employed by (Rose et al., 2000a), with reports of decreased VRQOL in patients with high myopia and keratoconus. Another study using the Vision and Quality of Life (VisQoL) instrument reported reduced VRQOL with spectacles and contact lens wear compared to emmetropes and post-refractive surgery patients (Chen et al. 2007). However, there has yet to be an investigation into the VRQOL of young adults in Singapore with respect to the refractive correction.

This thesis will report the prevalence of refractive errors, the ocular biometry distribution, and the changes in refraction and ocular biometry in Singapore young adults over two years. In addition, this thesis will also report the VRQOL in participants with different refractive correction and refractive error types, as well as the change in VRQOL over two years using the National Eye Institute Refractive Error Quality of Life Instrument (NEI-RQL-42). A total of 100 participants were recruited from the student pool of Ngee Ann Polytechnic. Data was collected for this research between January 2013 and April 2016.

1.1. Definition of Myopia

Myopia is a refractive disorder where light that enters an unaccommodated eye focuses in front of the retina (Curtin, 1985). Myopia is the result of excessive refracting power of the cornea and the crystalline lens to allow accurate focus at the fovea, which is often a result of axial elongation of the globe. The inverted defocused image cast on the retina of a myopic eye is perceived by the individual to be blurry but upright. The most common form of myopic correction is with the use of a negative powered lens that is placed in front of the eye. The diverging light rays that exit the lens of an appropriate negative power is then refracted by the cornea and the crystalline lens onto the fovea to provide clear and corrected vision. The appropriate power of the negative lens is measured in dioptres. The diagnosis of myopia is made when the spherical power of the eye is of a negative sign, typically -0.25 D or more negative, depending on the definition adopted by each research study.

1.1.1. Classification of Myopia

Through research and observation, it is now known that different categories of myopia exist. Researchers have attempted to classify myopia in order to examine and understand the aetiology, progress and outcome for each type of myopia, where clinicians would be able to advise patients on the treatment approach. Donders (1864) categorised myopia based on how it progresses, and described Stationary Myopia as low levels of negative refractive error that stop progressing in the teen years, while Temporarily Progressive Myopia was between -4.00 D to -8.00 D that stops progressing in the mid-twenties, and Permanently Progressive Myopia that encompasses higher degrees of myopia that continue to progress throughout life. The Textbook of Ophthalmology provided simplified classifications, where Simple Myopia begins in the first decade of life, stabilising in the teenage years, while Degenerative Myopia is associated with high levels of refractive error and degenerative changes in the retina (Duke-Elder, 1936).

Myopia can be also be defined by its aetiology, where Axial Myopia is a result of excessive elongation of the globe, and Refractive Myopia describes the discoordination of the major refractive components such as the cornea or the crystalline lens to result in myopia (Emsley, 1948). Sorsby (1956) proposed two categories of myopia, where refractive errors of 4.00 D or lesser were considered to be a result of mismatch of refractive components, and patients with refractions more than 4.00 D were mainly axial in origin. The work by Sorsby paved the road towards myopia classification based on the magnitude as well as the time of onset, where Goldschmidt (1968) introduced the terms Low Myopia, Late Myopia, and High Myopia. Goldschmidt described Low Myopia to be the most common form with slow progression that did not reach the level of High Myopia which is associated with degeneration and vision impairment. Late Myopia was described as onset of myopia after the individual reaches adulthood, which usually remains in the low levels.

Curtin (1985) further proposed Physiologic Myopia to be due to mismatch between the refractive powers and the axial length, while the major components continue to be of normal distributions. Intermediate Myopia was defined as the elongation of the globe that exceeds the normal range of growth, which included congenital myopia, childhood myopia, and late-onset myopia. Pathologic myopia, according to Curtin, was associated with degenerative disease as a result of uncontrolled axial growth. Grosvenor (1987) recognised the need to improve on how myopia could be classified, proposing Congenital Myopia to be present in new-borns which continued throughout life, Youth-onset Myopia to commence from a schooling age of six years, Early Adult-onset that develops between 20 and 40 years of age, and Late Adult-onset, which starts after the age of 40.
Myopia can also be defined based on the associated circumstances. The term School Myopia has been used to describe myopia of a youth-onset, which appears when children start to attend school (Sorsby, 1932). Pseudomyopia occurs when accommodation is not sufficiently relaxed during refraction testing, resulting in a myopic or a falsely more

negative finding (Walker, 1946). Index Myopia, on the other hand, is due to the increase in refractive index of the crystalline lens causing defocus in the myopic direction (Pan et al., 2013a). In modern times, myopia is more commonly classified by its degree, where Low Myopia is usually -3.00 D or better, Moderate Myopia is between -3.00 D and -6.00 D, and High Myopia is -6.00 D or worse. Pathological or Degenerative Myopia is used to describe myopia, which usually is high, that has caused degenerative change to retinal tissues (Grossniklaus and Green, 1991). The classification system proposed by Grosvenor continues to be of relevance, where the time of onset provides valuable prognostic information of the eventual level of myopia and its associated complications.

1.1.2. Prevalence of Myopia Around the World

Myopia is one of the most common ocular abnormalities managed and treated by eye care professionals around the world (Saw et al., 1996; Kempen et al., 2004). The simple management of using spectacles or contact lenses for myopia understates the far-reaching extent of this condition. It was estimated that the prevalence of myopia greater than -1.00 D was 25.4 %, 26.6 %, and 16.4 % for adults 40 years of age or older in the United States, Western Europe, and Australia, respectively (Kempen et al., 2004). In China, the prevalence of myopia worse than -0.50 D and -1.00 D was at 22.9 % and 16.7 % respectively in adults 40 years and older (Xu et al., 2005). However, in Singapore and Hong Kong, the prevalence of myopia worse than -0.50 D was substantially higher at 38.7 % and 40 % respectively (Van Newkirk, 1997; Wong et al., 2003).

The prevalence of myopia in children, especially the consequences they suffer when they become older, is of particular concern. Myopia in Australian children between five to eight years of age was reported to be low at 1.43 % (Ojaimi et al., 2005), where it increased to 5.1 % for European Caucasian children and 41.6 % for children of East Asian origin in the seventh year (Rose et al., 2008a). The Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) Study (based in USA) reported a myopic prevalence of

10.1 % in school aged children with a mean age of 10.0 ± 2.3, and myopic progression with increasing age (Zadnik et al., 2003). Research that exclusively investigated Asian children has reported prevalence findings that are much more severe. In the early part of the 21st Century in Singapore, 29.0 % of children were myopic at seven years of age, while 53.1 % of children were myopic at nine years of age (Saw et al., 2002a). In Hong Kong, 36.7 % of children aged between six and 15 were reported to be myopic (Van Newkirk, 1997). In the Shanxi County of China, myopia was reported to be absent in five year olds, and at 36.7 % for males and 55 % for females in 15 year olds (Zhao et al., 2000). A stark contrast can be observed in the work of He et al. (2004) where myopic prevalence was reported to be between 3.3 % and 5.1 % at five years old age and between 73.1 % to 78.4 % for 15 year olds; this can be attributed to the difference in environment where Shanxi County is a rural farming community outside the capital of Beijing, while the work of He et al. was based in Guangzhou city. The environmental factors that can contribute to higher myopic progression and prevalence are described in Section 1.3.5.

The higher prevalence of myopia in East and Southeast Asian populations compared to Western countries is of particular interest. Children of Asian origin are reported to have a higher prevalence of myopia than children of European origin. Finally, children in urban cities exhibited higher myopia prevalence rates than children living in rural areas.

1.1.3. Implications of Myopia in Singapore

It is estimated that Singaporeans spend more than $311.5 million on corrective spectacles each year (Lee, 2013; Singapore Department of Statistics, 2013). This economic burden is primarily caused by the public health problem of myopia. It is not uncommon for parents to consider a pair of spectacles as one of the items to buy before school opens for a new academic year (Channel News Asia, 2014). With increasing demand for primary eye care professionals, a second optometry programme in Singapore was started in 2008 by Ngee

Ann Polytechnic to increase the number of optometry graduates. This in turn increases public spending in the training of optometrists ("Ngee Ann opens $1.2M Optometry Centre," 2013). With the increasing popularity of refractive surgery for permanent myopic correction, many have opted for this mode of correction (Wee et al., 1999; Yuen et al., 2010) which can be more cost effective long-term (Javitt and Chiang, 1994).

Worried parents may consider the various modes of treatment that can potentially arrest or retard the progression of myopia. Such treatments include atropine eye drops (Chia et al., 2012; Chua et al., 2006), orthokeratolology (Cho et al., 2005; Kakita et al., 2011), bifocal (Cheng et al., 2010; Fulk et al., 2000; Goss and Grosvenor, 1990) and multifocal ophthalmic lenses (Gwiazda et al., 2003; Hasebe et al., 2008; Leung and Brown, 1999; Yang et al., 2009), specialised ophthalmic and contact lenses (Anstice and Phillips, 2011; Sankaridurg et al., 2010) or other lesser known and untested devices such as the EyeRelax ("EyeRelax Device - Improve Shortsightedness Naturally," 2014.). Although championed by orthokeratologists as an effective treatment for slowing myopic progression, orthokeratology has raised concerns amongst ophthalmologists in Singapore due to the potential risks of microbial keratitis (Chee et al., 2007). Myopia is also associated with other potential complications such as glaucoma (Mitchell et al., 1999), peripheral chorioretinal changes (Pierro et al., 1992), retinal detachment, and myopic macular degeneration (Shih et al., 2006).

Since the defence force of Singapore is largely conscripted, the government has devoted resources into studying how myopia can affect the operational readiness of servicemen ("Advancing Defence Medical Research through Joint Collaboration: State-of-the-Art Research Complex Opens at NUS Campus," 2005). It has previously been shown that soldiers can be burdened by the need to use spectacles or contact lenses during active operations (Rabin, 1996). The requirement for good eyesight has also made the selection of Air Force pilots a difficult task (Ng, 1994). It was estimated that 44.2 % of military conscripts between 1987 and 1992 had correctable visual impairment caused by myopia (Tay and Lim, 1993); this was a substantial increase in the prevalence of myopia where it was only 26.3 % between 1974 and 1984 (Tay et al., 1992). The authors attributed the increase in prevalence to the rising number of males completing tertiary education before enlisting into military service. The myopic prevalence rates of military conscripts who completed primary, secondary and tertiary education was 14.2 %, 22.2 % and 63.6 % respectively (Wu et al., 2001). As the number of tertiary graduates increases every year (Singapore Department of Statistics, 2013), the myopia problem for the military is expected to worsen.

1.2. Ocular Biometry and Myopia Development

At birth, the human eye typically exhibits hyperopia, where the process of emmetropisation is likely to be completed in the first year of life (Saunders, 1995). Emmetropisation is the process of refractive error reduction in neonates during the initial stages of ocular growth. Early research suggested that the axial length increases with eye growth, where the cornea and the crystalline lens compensate by a reduction in refracting power (Hirsch and Weymouth, 1947; Stenstrom, 1948; Sorsby, 1956; Sorsby et al., 1960), which demonstrated the existence of interdependent relationships between the cornea, crystalline lens and the axial ocular growth, in order to achieve emmetropia. The distribution of refractive error at birth was reported to be of a Gaussian distribution that centres at hyperopia (Steiger, 1913; Sorsby, 1956; Sorsby et al., 1962). The Gaussian distribution would evolve to a leptokurtic distribution where emmetropia represents the majority of the refractions in adulthood. While the individual parameters such as the corneal power, anterior chamber depth, crystalline lens power and the axial length follow the Gaussian curve, Sorsby described the non-Gaussian distribution of refraction to be a result of the amalgamation of these interdependent components .

In early studies of ocular components, corneal curvature was reported to be stabilised after the age of one (York and Mandell, 1969). The cornea undergoes a process of rapid flattening in the initial two to four weeks and eventually stabilises by the eighth week of life (Inagaki, 1986). During the emmetropisation process, the changes in corneal curvature and crystalline lens are more likely a result of a coordinated change, together with axial length growth, as postulated by mathematical models (Dunne, 1993). While the cornea continues to flatten during growth, in tandem with axial elongation, Wood et al. (1996) reported higher refractive indices in infantile crystalline lenses and proposed that a decrease in the refractive index of the crystalline lens occurs rather than its flattening. Sorsby (1956) found myopes to exhibit steeper corneal curvature compared to emmetropes and hyperopes, suggesting the failure of the cornea to flatten to continue the emmetropisation process in myopic eyes. Most early studies were not able to accurately measure the crystalline lens thickness and calculate its power, thus were unable to present a full picture of how the ocular components change with eye growth.

1.2.1. Refraction and Ocular Biometry in Youths

Myopia can be classified according to the age of onset (Grosvenor, 1987), which helps to differentiate between youth-onset myopia and early adult-onset myopia. Youth onset myopia arises at around six years of age and usually stops progressing at around 15 or 16 years of age (Goss and Winkler, 1983). Caucasian children have been shown previously to exhibit predominately low hyperopic refraction at the age of six, which decrease towards emmetropia by the age of 12 (Zadnik et al., 1993). Garner et al. (1988) reported similar findings where mild hyperopia and emmetropia were found in 96.8 % of Melanesian schoolchildren in Vanuatu. Despite the differences in the ethnic groups in these studies, similarities could be drawn. Results from ocular biometry showed no significant differences in corneal curvature with increasing age. The low prevalence of ametropia in the Vanuatu study was possibly attributable not only to genetics, but also to the non-urban environment. The Correction of Myopia Evaluation Trial (COMET) recruited children with myopia between the ages of 6 and 11 years and examined the refraction and ocular biometric components baseline data (Gwiazda et al., 2002). It was not surprising that older children had longer axial length than younger children. However, there were differences between girls and boys, where girls had significantly shorter axial lengths and vitreous chamber depths, and steeper corneal curves, which were confirmed by Saw et al. (2002a) and Zadnik et al. (2003).

The Orinda Longitudinal Study of Myopia (OLSM) was a two-year longitudinal study that commenced in 1989 in California which examined two cohorts of Caucasian children, aged between 6 and 14 years, and reported ocular biometric findings during this crucial period of growth where myopia development would most likely occur (Zadnik et al., 1993).

Mean vitreous chamber elongation of 0.52 mm, crystalline lens power reduction of 1.35 D, and thinning of the crystalline lens by 0.14 mm were reported. The thinning of the crystalline lens occurs at an early period of between six and eight years, while the anterior chamber depth increased by 0.22 mm from 6 to 12 years. An investigation into the emmetropic children of the OLSM found that while axial elongation occurs during ocular growth, the crystalline lens flattened, thinned, and decreased in its refractive index and refractive power in order to maintain emmetropia (Zadnik et al., 2004). The cornea did not appear to play any role as it only flattened minimally (by 0.06 D) in these emmetropic children. The Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE), a multi-centre observational study, investigated the refractive error and ocular biometry of 2,583 children, with an average age of 10.0 ± 2.3 years, found 10.1 % and 8.6 % of the children to be myopic and hyperopic, respectively (Zadnik et al., 2003). The CLEERE investigated the overall trend of ocular growth of children from various ethnic groups, and found that girls had shorter axial lengths, as well as stronger cornea curves and lens power. Conversely, male gender and older age were found to be related to deeper anterior chamber depths. While the crystalline lens appeared to thin with age, there was no association between corneal curvature and age.

In Asia, the prevalence of myopia is markedly higher - 12 % and 15 % of schoolchildren in Taiwan were myopic at six years and 12 years of age, respectively (Lin et al., 1999). The figures were substantially higher for 15 year olds, at 76 %. A cross-sectional study in Singapore that performed A-scan contact ultrasonography and cycloplegic auto-refraction for children between 7 and 9 years of age also found higher prevalence rates of myopia, at 29.0 % (Saw et al., 2002a). The Singapore study took into consideration the factors that could have contributed to myopia, and concluded that children of older age, male gender, and reading of more than two books a week, with at least one myopic parent tended to exhibit longer axial lengths and longer vitreous chamber depths.

1.2.2. Distribution and Correlations of Ocular Components and Refractive Error

Early studies reported refraction to be of a Gaussian distribution at birth (Steiger, 1913; Sorsby, 1956; Sorsby et al., 1962), which would eventually develop into a leptokurtic distribution as a result of emmetropisation. The distribution of refraction would eventually be dependent on the characteristics of the population as some communities are more prone to refractive changes (e.g. myopia development) compared to others due to either genetics or environmental factors. Ojaimi et al. (2005) reported the refraction of 1,765 schoolchildren of age 5 to 8 to be leptokurtic with a minute positive skew. Ip et al. (2007) reported similar findings with refraction distributions of six-year-olds as well as 12-year-olds, where the kurtosis was 14.4 and 11.3, respectively. The authors suggested that the leptokurtic distribution of refraction implied the dissociation between cornea curvature and axial elongation. As such, the kurtotic distribution of refraction was evident in the emmetropisation process during infancy (Mayer et al., 2001)

1.2.3. Refraction and Ocular Biometric Changes in Young Adults

As proposed by Grosvenor (1987), early adult-onset myopia is identified as myopia development between the ages of 20 and 40 years. Interestingly, an investigation of the TwinsUK cohort showed that 11.4 % had myopic onset between 17 and 19 years of age (Williams et al., 2013). This section will review the research that investigates myopic rates and progression in young adults around 17 to 19 years of age, as listed in Table 1.1.

Kinge et al. conducted a three year study to investigate ocular biometric changes in university students in Norway (Kinge et al., 1999; Kinge and Midelfart, 1999). It was reported that the mean progression of myopia was SE -0.57 D over three years with accompanying vitreous chamber elongation. The proportion of myopes, defined by the authors as SE ≤ -0.25 D, increased from 48 % to 65 %. Myopes at baseline had higher amounts of myopic change compared to hyperopes and emmetropes. There was also no biometric difference at baseline between emmetropes who became myopic and those who did not, negating the possibility that ocular biometry may be used for prediction of myopic development. It was interesting to note that the current reading habits of the participants were not associated with the change in myopia. Onal et al. (2007) followed medical students in Turkey for a year, but found no significant change in refraction or ocular biometry. The questionnaire given to the medical students revealed 14.7 % had adult-onset myopia. Parental myopia was reported to be an independent risk factor for myopia, while outdoor activities were considered to be protective of myopia.

Following the refractive, ocular biometric and corneal topographical change in Portuguese university students in a three year longitudinal study, Jorge et al. (2007) reported that the prevalence of myopia (defined as ≤ -0.50 D) increased by 5.1 % while the prevalence of hyperopia increased by 9.4 %, and that 22 % of participants had myopic progression of at least SE 0.50 D. There were significant changes in axial length, crystalline lens thickness and vitreous chamber depth, but no change was reported for anterior chamber depth or keratometry. Lin et al. (1996) examined the refraction of Taiwanese medical students during their first year, and compared the findings to the fifth year. The authors reported that 92.8 % of the medical students were myopic (defined as SE ≤ -0.25 D) which increased significantly to 95.8 %, over the five years in medical school. Axial length was found to be the key ocular biometric change.

Lv and Zhang (2013) reported increased myopia rates (defined as SE ≤ -0.50 D), from 78.5 % to 84.1 % in medical students in China. Medical students from rural areas were found to exhibit larger increases in myopia. It is obvious that Chinese students exhibited the highest rate of myopia, from 78 % to 96 %, while the myopia occurrence in Europeans tended to be lower at 33 % to 66 %. However, Logan et al. (2005) reported that there was no significant difference in the prevalence of myopia between British White students and British Asian students, at 50 % and 53.4 % respectively. It was suggested that the British Asian students experienced the same learning environment as the British White students, and may have a lifestyle that is distinct from Asian students that originate from East Asia. The myopigenic environment appears to play a significant role that may be independent of ethnicity as proposed by Morgan and Rose (2005).

Myopic progression was observed in all the longitudinal studies in Table 1.1 with the exception of the Turkey study; this paper also reported a relatively low prevalence of myopia, at 32.8 % (Onal et al., 2007). This could be attributed to the authors' definition of myopia at SE -0.75 D or lesser. A one year longitudinal study may have been inadequate to effectively determine the progression of myopia in young adults, as progression may occur at a slower rate compared to younger school children (Grosvenor and Scott, 1993; Saw et al., 2005). Change in refraction was also reported to be related to the increase in vitreous chamber depth and axial length, which is in accordance to earlier research by Grosvenor and Scott (1993). Although it has been ascertained that the rate of myopia is also high in Singapore medical students (Chow et al., 1990; Woo et al., 2004), there is a lack of longitudinal information in this area. Moreover, few studies have investigated the longitudinal change in refraction and ocular biometry in the younger age group that is between 16 and 21 years of age.

Location	Study Design	Sample	Author	Age	Definition of Myopia	Proportion of Myopes	Change / Results
National Taiwan University, Taiwan	5 Year Longitudinal	Medical Students	Lin et al. (1996)	18 to 21	≤ -0.25 D	92.8 % to 95.8 %	Ref Change: 0.70 ± 0.65 D AL Change: 25.54 ± 1.28 to 26.05 ± 1.21 (males) AL Change: 24.60 ± 1.35 to 24.95 ± 1.21 (females)
University of Trondheim, Norway	3 Year Longitudinal	Engineering Students	Kinge and Midelfart (1999); Kinge et al. (2000)	20.6 ± 1.2	≤ -0.25 D	49 % to 66 %	Ref: -0.51 ± 0.49 59 % of emmetropes became myopes 73 % of myopes progressed 8 % of hyperopes became myopes Ref Change: -0.52 ± 0.45 AL Change: 0.34 ± 0.31 LT Change: 0.07 ± 0.10 VCD Change: 0.27 ± 0.30
University of Minho, Portugal	3 Year Longitudinal	Optometry Students	Jorge et al. (2007)	20.6 ± 2.3	≤ -0.50 D	22 % to 27.1 %	Ref Change: -0.29 ± 0.38 D AL Change: 23.39 ± 0.93 to 23.50 ± 1.00 VCD Change: 16.15 ± 0.85 to 16.22 ± 0.93 LT Change: 3.63 ± 0.14 to 3..69 ± -/16
Marmara Univeristy, Turkey	1 Year Longitudinal	Medical Students	Onal et al. (2007)	18 to 26	≤ -0.75 D	32.9 %	14.7 % are Adult-Onset Myopia No significant shift in Ref
Weifang Medical University, China	2 Year Longitudinal	Medical students	Lv and Zhang (2013)	20.3 ± 1.8	≤ -0.50 D	78.5 % to 84.1 %	Ref Change: -2.52 ± 2.13 D to -2.84 ± 2.16 D

Table 1.1 Studies that had investigated ocular biometry and refraction in young adults. There are no published longitudinal studies that report ocular biometry and refraction of young adults in Singapore.

1.2.4. Techniques to Measure Ocular Biometry

A-scan ultrasound echography, also known as A-scan biometry, is a widely used technique to perform ocular biometry measurements (Waldron and Aaberg, 2016). It employs a high frequency of around 10 MHz, depending on the manufacturer, to penetrate the ocular media. As sound travels through structures of different density at varying speeds, the echo that is reflected off the interface of each ocular structure is analysed to provide measurements. The disadvantages of A-scan biometry are inaccuracies produced by obliquely positioned probes, as well as unintended applanation of the corneal surface (Binkhorst, 1981; Giers and Epple, 1990). In addition, topical anaesthesia is required when performing this technique. As such, A-scan biometry has become a less favourable technique since the emergence of optical biometers.

The IOL Master (Carl Zeiss Meditec AG, Jena, Germany) was the first optical biometer that was able to perform non-contact ocular biometry measurements (Drexler et al., 1998). It uses the partial coherence interferometry technology, and is able to perform automated keratometry. During measurement, a 780 nm partial coherent light is divided and phase-delayed by the interferometer, where one beam of light is reflected off the cornea, while the other passes through to the posterior eye and is reflected off the retinal pigmented epithelium. An inbuilt photodetector analyses the interference pattern of the two beams of light to provide accurate measurement of the ocular structures. The IOL Master uses a slit beam that is approximately 30 degrees from the visual axis to measure the anterior chamber depth.

The Lenstar LS900 (Haag Streit AG, Koeniz, Switzerland), an optical biometer that was used in the present study, employs Optical Low-Coherence Reflectometry (OLCR) to perform non-contact measurements of ocular structures. The capability of the Lenstar

LS900 is made possible by the use of a superluminescent diode with a Gaussian-shaped spectrum at a wavelength of 820 nanometres. This allows the instrument to capture high resolution axial measurements. During measurement, low-coherent light is emitted from the diode, where reflection occurs at the surfaces of ocular structures. The transparent ocular medium allows the transmission of the low-coherent light until it is absorbed by the retinal pigmented epithelium. The interferometer in the Lenstar LS900 interprets the reflected light to determine the precise depth of each ocular structure surface. OLCR has been shown to provide highly repeatable measurements of corneal curvature, corneal thickness, anterior chamber depth, crystalline lens thickness, and axial length (Cruysberg et al., 2010).

Although statistically significant differences in ocular biometric measurements of the Lenstar LS900 were reported when compared with contact A-scan biometery and the IOL Master, they were not considered to be clinically significant (Buckhurst et al., 2009). This finding was confirmed by Cruysberg et al. (2010), where statistical significant but clinically insignificant differences were found between the Lenstar LS900 and the IOL Master. High correlation and agreement exists between the Lenstar LS900 and the IOL Master, even with cataractous and pseudophakic eyes (Rohrer et al., 2009; Hoffer et al., 2010; Rabsilber et al., 2010; Salouti et al., 2011).

The Lenstar LS900 performs several ocular biometric measurements in a single measurement, where 16 scans are performed consecutively, allowing high repeatability as each measurement only takes less than 10 seconds. As such, the Lenstar has been found to provide precise ocular biometric measurements to be used for intraocular lens power calculations (Holzer et al., 2009; Cruysberg et al., 2010). In addition, Shammas and Hoffer (2012) found the ocular biometric measurements of the Lenstar LS900 to be highly repeatable and reproducible for 37 patients over a one month period.

1.3. Risk Factors for Myopia

1.3.1. The Genetic Makeup

The genetic makeup of a person determines how each part of the body develops and functions, and thus may determine if a person is susceptible to myopia development (Morgan and Rose, 2009). However, debate often evolves around whether it is genes that solely cause the myopia that will eventually develop later on in life, or the possibility that genes provide the susceptibility for environmental influences to cause axial elongation. Gene-environment interaction can be either different genotypes responding to the same environment or particular genotypes that are more susceptible to change due to the environment (Martin, 2000; Saw et al., 2000; Morgan and Rose, 2009; Chen et al., 2011). As such, genetic make-up cannot be discounted from myopigenesis. Scleral remodelling and excessive axial elongation have been demonstrated to be attributed to the hepatocyte growth factor (HGF) and the transforming growth factor beta1 influenced by the genes (Han et al., 2006; Yi et al., 2009). The growth factors and single nucleotide polymorphisms (SNPs) have been shown to be associated with a severe form of myopia that can lead to complications such as macular degeneration, retinal tears, and retinal detachment (Shi et al., 2011; Tran-Viet et al., 2012). However, Yanovitch et al. (2009) demonstrated a strong relationship between HGF and mild to moderate myopia, while Hysi et al. (2010) have established SNPs on the locus 15q25 to be associated with myopia in a 4,270 Twins UK cohort, and replicated on myopic individuals in a cohort of 13,414.

Although many studies have demonstrated genetic associations with myopia, specific genes have not been identified as a direct cause of myopia development due to the heterogeneous nature of myopia. While specific genes have been shown to contribute to the severe myopia that is often associated with other systemic conditions, there could be multiple genetic interactions in the common school myopia that affects many children. While we await more research to establish clearer genetic associations to school myopia, it is crucial to investigate the potentially modifiable environment where gene-environment interactions take place (Saw et al., 2000; Lyhne et al., 2001).

1.3.2. Twin Studies

To better understand how genetics plays a role in the development of myopia, studies on monozygotic twins have been performed due to them having the same genome, and very often, similar environment, lifestyle and habits (Chen et al., 1985). Researchers have correlated the refractive error between the siblings of each pair of twins, and compared the findings from the monozygotic twins group with the dizygotic twins group. This has shown to demonstrate a very high rate of heritability between 75 % to 94 % (Dirani et al., 2006; Hammond et al., 2001; Lyhne et al., 2001). Such studies have suggested that heritability plays a large role in refractive errors and that the environmental effects are minimally significant. Chen et al. (2007) examined the family and childhood shared environment to demonstrate a much lower heritability of 50 % for refractive error; this marked difference in heritability is largely due to the investigation of familial pedigrees with their respective shared environments instead of twins. Investigating further, Lopes et al. (2009) reported only 7 % and 16 % of refractive error being accounted for by the shared environment and unique environment respectively. The authors thus proposed that twin studies are better suited for investigating the heritable effects of myopia, while family studies are more appropriate for examining the shared environmental effects. Nonetheless, educational attainment was reported to be associated with genes in the Genes in Myopia Twin Study (Dirani et al., 2008).

Due to the identical genome of monozygotic twins, twin studies are able to demonstrate the high correlation of refractive error and ocular biometry between each twin sibling. The susceptibility of developing myopia is likely to be determined in each twin's genetic make-up. The heritability of myopia from these twin studies may influence the understanding of the aetiology of myopia. However, it is imperative to consider that during the childhood years when myopia usually develops, twins usually share identical environments and may have similar reading and lifestyle habits, often determined by their parents. As such, the environmental effect that may interact with their genetic disposition may not be appreciated in twin studies. Research is needed to investigate siblings or even monozygotic twins who have disparate growing-up environments that result in different amounts of myopia in each sibling.

1.3.3. Parental Myopia

Studies on parental myopia have investigated the effect of heritability of genomes for refractive error and myopia. Pacella et al. (1999) reported that children who were in the lower half of the refractive error distribution (less hyperopic) when they were one year old or younger were 4.33 times more likely to develop myopia compared to children who were in the upper half of the distribution (more hyperopic). In the second stage of the study, it was found that the children who were in the lower half of the refractive error distribution (lesser hyperopia) and had two myopic parents were 42 times more likely to develop myopia compared to children who were in the upper half of the distribution, whether they had one or no myopic parents. Wu et al. (1999) examined three generations of Chinese participants, concluding that the odds of developing myopia were greater for each subsequent generation. Although a genetic influence appears to be present, this same trend was also present in non-myopes of the first generation and second generation. Apart from genetic inheritance of myopia, the study demonstrated the possible role of other factors such as the environment, resulting in increasing odds of myopia development in descendants with non-myopic parents. The result is concurrent with another report in Singapore where children with myopic parents exhibited more myopic progression than children with non-myopic parents (Saw et al., 2001). It is apparent that parental myopia may be a predictor for myopia development, and yet myopia progression can still occur without myopic parents, albeit with lesser magnitude.

Since parental myopia greatly influences the odds of myopia development, it is possible that it could either be a surrogate measure for genetic disposition as suggested by Morgan and Rose (2009), or possibly the influence of myopic parents on their children's increased amounts of near work. However, some studies have shown that near work is not a significant factor that causes the increase in myopia (Mutti et al., 2002; Ip et al., 2007). Mutti et al. reported that the myopigenic environment could not be inherited from the myopic parents, and that having two myopic parents could not result in an increase in the susceptibility to myopia due to near work. Ip et al. surveyed the amount of time children spent on nearwork and found that the mean spherical equivalent refraction did not differ between high, moderate and low levels of nearwork, confirming the findings by Mutti et al. that near work is not a significant risk factor in myopia development. The significant relationship between parental myopia and the children's myopia was underscored by the East Asian children's higher prevalence in myopia and greater associations with parental myopia.

Since the exact genes for myopia have yet to be conclusively identified, parental myopia remains a useful surrogate for myopia heritability as suggested by Morgan and Rose (2009). The perceived odds of a child developing myopia based on the parents' refractive status may be useful clinically, although it should be used with caution as not all studied samples may represent the population. In addition, there may need to be a reduced emphasis on the risk of increased near work and its role in myopigenesis.

1.3.4. Near Work

Near work refers to tasks visual tasks that are held within an arm's length which require accommodative effort. The tension of the ciliary muscle as a result of the accommodative effort required for reading has been implicated in axial elongation (Angle and Wissmann, 1978). As such, near work has long been postulated to be a potential risk for myopia development (Richler and Bear, 1980; Zylbermann et al., 1992). For years, studies have been performed in the attempt to establish this association. A longitudinal study in Norway reported that intensive near work resulted in an increase in myopia in university engineering students, and that the association was statistically significant with reading scientific literature and attending lectures (Kinge et al., 2000). Surprisingly, the use of computer screens was not related to myopic progression. In a cross-sectional study by Saw et al. (2001b), no associations between near work and myopia were found in military conscripts in Singapore. Near work was also not found to be related to myopia for military conscripts in Greece (Konstantopoulos et al., 2007). The conscripts had to recall the amount of reading in the last four years; the quantification of recent near work would not correlate well with myopia as the participants are adults and their near work habits would have changed compared to the childhood years when their myopia was developing, especially when the research design was not longitudinal.

In a cross-sectional study on children between 7 and 9 years of age, the number of books read per week was associated with myopia but not the quantity of near work (Saw et al., 2002b). However, when children in Singapore were compared with children in Xianmen, China, there was a significant difference in the amount of reading, with Singapore children reading 4.1 hours more per day (Saw et al., 2002). When the children from these two countries were combined, near work became a statistically significant factor for myopia. In this instance, the disparate amount of near work between both countries could have increased the significance of the association of near work with myopia. The Sydney Myopia Study examined 2,353 children for their near work activities and habits where closer reading distance and continuous reading were found to be associated with myopia, but not other near work activities or parameters (Ip et al., 2008b). In particular, East Asian children were reported to have greater odds of developing myopia and spent more time performing near work activities than Caucasian children. In contrast, myopic children in rural China were found to perform similar amounts of near work as non-myopic children (Lu et al., 2009). However, myopic children consistently reported shorter working distances for all near activities than non-myopic children, which is in concurrence with the Sydney Myopia Study's findings. The academic environment in rural China may have been a protective effect for the children there, as compared to children living in the city and exposed to higher academic pressures. It is also possible that high academic demand could continue to cause myopic progression even in early adulthood, as demonstrated by Kinge et al. (2000).

To date, most research studies that have investigated near work as a risk factor for myopia have been cross-sectional in design, which could not effectively establish a cause-effect relationship between near work and myopia development. Quantification of near work often requires the completion of a questionnaire which could result in recall bias (Raphael, 1987; Coughlin, 1990). Adult participants may find it difficult to remember their reading habits from years ago, thereby affecting the accuracy of the results. Although still subject to possible reporting bias, it would be easier for parents to recall the current reading habits of their children. Yet, there are inadequate longitudinal studies in the area of near work. From the literature reviewed, it is apparent that near work is not a conclusive risk factor for myopia and the relationship between near work and myopia established in some studies could be confounded by other environmental factors such as academic pressures.

1.3.5. The Urban Environment

The prevalence of myopia is especially high in modern and urbanised cities or states such as Singapore (Tay et al., 1992; Seet et al., 2001), Taiwan (Lin et al., 2004), Hong Kong (Goh and Lam, 1994; Edwards and Lam, 2004) and South Korea (Yoon et al., 2011) In Taiwan, there was an increase in the prevalence of myopia from 1983 to 2000; from 5.8 % to 21 %, 36.7 % to 61 %, 64.2 % to 81 %, and 74 % to 84 %, in seven years old, 12 years old, 15 years old, and 16 to 18 years old at baseline respectively (Lin et al., 2004). The increasing prevalence occurred at different rates in various locations. Cities such as Taipei and Kaohsiung saw the greatest increase in prevalence rates, while remote and hilly areas had the lowest increase in prevalence.

Singaporean Chinese children also exhibited higher prevalence of myopia compared to Chinese children in Xiamen, China (Zhang et al., 2000). Singapore is a city-state with a land area of only 716 km^2, where all children are living in an urbanised environment. In contrast, the study population in Xiamen encompassed children from schools in both the city and the countryside. As such, it is possible that the children studying in the countryside schools were not exposed to the urbanised environment in the city, leading to the reduced myopic prevalence. In neighbouring Malaysia, the prevalence rates of myopia were also statistically significantly lower in the Chinese, Malay and Indian ethnic groups, as compared to Singapore (Saw et al., 2006); this is of particular interest, as the people from both countries share common heritage. However, the study suffers from selection bias, where the sample may not be representative of the population, and that it did not investigate near work as a confounding factor.

Numerous studies have reported a higher prevalence of myopia in children living in cities as opposed to those living in rural areas (L. L. K. Lin et al., 2004; He et al., 2009; Guo et al., 2013). Guo et al. compared the potential contributing factors of myopia between urban and rural Beijing children. It was reported that children were more likely to be myopic if they spent more time studying indoors, less time on outdoor activities, and if there was maternal myopia. Since the prevalence of myopia is associated with the rising levels of education opportunities and attainment (Wu et al., 2001; Morgan and Rose, 2013), it is possible that the living environments for children present with reduced time for outdoor activities, which has been shown to be protective of myopia development (Rose et al., 2008a; Dirani et al., 2009). Chinese children in Sydney who spent more time outdoors, despite doing more near work activities, have been shown to developed lesser myopia than Chinese children in Singapore (Rose et al., 2008b). Consistently, parental myopia has been reported to be an important risk factor for myopia development (Mutti et al., 2002; Ip et al., 2007; Jones-Jordan et al., 2010). While there is no conclusive evidence for the heritability of acquired myopia where onset occurs during school-age, myopic parents may unknowingly create a living environment that focuses on academic achievement, thereby sacrificing outdoor activities (Rose et al., 2008a; Morgan and Rose, 2009).

1.3.6. Education

The emphasis of education in urban environments appears to have a significant effect on myopia. Mutti et al. (2002) reported that children with myopia achieved better reading and language test scores. Intelligence and educational achievement have been suggested to be related to myopia development (Ashton, 1985; Cohn et al., 1988). In Singapore military conscripts, servicemen who were in the gifted, express or special streams during secondary school education exhibited higher myopia as opposed to those who were in the normal stream (Saw et al., 2001b). Servicemen who had optional additional tuition classes during primary school were also associated with higher myopia than those who did not have tuition classes. The use of additional tuition classes is a phenomenon that is common in Asian countries (Morgan and Rose, 2013). Morgan and Rose demonstrated that countries with high education standards and extensive use of additional tuition classes have a higher prevalence of myopia. On the other hand, countries with high education standards and low prevalence of myopia do not use additional tuition classes.

The relationship between higher education attainment and myopia has been established (Tay et al., 1992; Tay and Lim, 1993; Wu et al., 2001). While it is suggested that genes may influence educational attainment (Dirani et al., 2008) and the myopigenic environment may be inherited (Saw et al., 2001a), it was also reported that there is no increased odds of myopia for having myopic parents given the same amount of near work (Mutti et al., 2002). It is possible that educational attainment is a surrogate for near work, where it is difficult to ascertain the accurate quantity, intensity and parameters of near work in practical research. The highest educational attainment used in research may also represent the cumulative effect of scholastic work that may contribute to school myopia.

While the prevalence of myopia has been shown to be higher in East Asians, the prevalence rates vary in different environments. The prevalence of myopia in East Asian 12 year old children in Australia was 55.1 % in the inner city, as compared to 29.2 % in the outer suburbs, after adjusting for parental myopia, age, sex, near work and outdoor activity (Ip et al., 2008). Outdoor activity showed a small protective effect from myopia. When comparing age-matched Chinese children in Singapore and Sydney, Singapore children had a higher prevalence of myopia at 29.1 % as compared to 3.3 % in Sydney (Rose et al., 2008b). It is notable that the Chinese children in Sydney read more books per week, had longer reading and writing time, and spent more time using a computer than Singapore children. Chinese children in Singapore had more additional tuition classes and much lesser outdoor activities as compared to their Sydney counterpart. Rose et al. (2008a) concluded that outdoor activities had a protective effect to prevent the development or worsening of myopia in the Chinese children in Sydney. The different school environments may also suggest that there is greater educational pressure and a stronger emphasis on education in Singapore.

1.3.7. Outdoor Activities

The cohort of the Sydney Myopia Study was re-examined for myopigenic activities by French et al. (2013), revealing that children tended to develop more myopigenic lifestyles when they grew older. There was a reported increase in near work activities and decrease in outdoor activities with age. East Asian children also exhibited fewer outdoor activities and greater near work compared to European Caucasian children. The findings of a cross-sectional study in Beijing on 382 grade 1 to 4 students found outdoor activities to be inversely and significantly associated with indoor near work (Guo et al., 2013). This inverse relationship was not supported by Guggenheim et al. (2012) and other studies where children who spent more time outdoors do not necessarily perform less near work (Jones et al., 2007; Rose et al., 2008a; Deng et al., 2010). A study in Taiwan compared two schools where one encouraged students to participate in outdoor activities while the other did not have such an initiative (Wu et al., 2013). The students who were from the school that encouraged outdoor activities during recess had lower incidences of myopia onset and progression compared to the other school. However, Jones-Jordan et al. (2012) did not find outdoor activities to be effective in preventing the progression of myopia, but only protects against the onset of myopia. A systematic review by Sherwin et al. (2012) reported that for every one hour of outdoor activities spent in a day, the reduction of risk for incident myopia is 2 %. However, more studies are warranted to reaffirm the effect of outdoor activities on preventing myopia progression.

From the findings of these studies, it can be suggested that East Asians, especially those who are not living in westernised countries, are likely to participate in fewer outdoor activities, perform more visual tasks such as reading or using the computer, and are more likely to engage in additional tuition classes (Morgan and Rose, 2013). These environmental factors most likely cause the higher myopic prevalence rates in East Asian children.

1.3.8. Accommodative Accuracy and Myopia Development

Accommodative response is the quantification of the amount of accommodation for a given accommodative stimulus. An accommodative response that is lower than the stimulus demand is termed accommodative lag, while accommodative response that is higher than the stimulus demand is termed accommodative lead. Accommodative responses can be measured by dynamic retinoscopy techniques (Rouse et al., 1982; García and Cacho, 2002; McClelland and Saunders, 2003), the fused cross cylinder technique (Goss, 1991; Rosenfield et al., 1996), or with the use of an open field auto-refractor (McBrien and Millodot, 1985; Davies et al., 2003; Sheppard and Davies, 2010). Since the open field auto-refractor provides consistent and objective results (Davies et al., 2003; Sheppard and Davies, 2010), this method is commonly used in research to evaluate accommodative responses (Mutti et al., 2006; Weizhong et al., 2008; Berntsen et al., 2011).

Gwiazda et al. (1993) described the measurement of accommodative response using the open field auto-refractor by decreasing the distance of the target (decreasing distance series), increasing the amount of negative lens power with a fixed target (negative lens series), or increasing the amount of positive lens power with a fixed high accommodative target (positive lens series). The authors noted that induced accommodation using lenses did not represent real life targets that are normally viewed. Abbott et al. (1998) confirmed the findings of Gwiazda et al. in that negative lens series produced the least accurate accommodative response curves, while the decreasing distance series and positive lens series yielded similar results.

Early studies implicated accommodative response as a link to myopia, where myopes were found to accommodate less accurately than emmetropes and hyperopes (McBrien and Millodot, 1986; Rosenfield and Gilmartin, 1988). Animal studies had shown that blur induced by either positive or negative lenses can have an effect on ocular growth, resulting in refractive errors (Irving et al., 1991, 1992; Hung et al., 1995). Since lag of accommodation results in some degree of retinal blur, it is postulated that lag of accommodation may result in myopic progression. Gwiazda et al. (1993) found that both myopic and emmetropic children had accurate accommodation to distance targets, while myopic children had significantly lower accommodative response to near objects than emmetropic children. In adults, Abbott et al. (1998) did not find any difference in accommodative response between early and late-onset myopes. However, when myopes were grouped into stable and progressing groups, progressing myopes exhibited greater accommodative lag with higher accommodative demand.

A one year longitudinal study was undertaken by Gwiazda et al. (1995) to investigate the accommodative response in children in relation to myopic progression. It was found that accommodative inaccuracy increases when myopia progresses, which subsequently improves as myopia stabilises. The worsening of accommodative accuracy with the reduction of working distance paradoxically improves the visual perceptibility of the near object, as reported by Charman (1999). Yet, Charman suggested that poor accommodation would lead to decreased contrast of the near task that is below threshold, eventually causing myopic change in refraction. The COMET study investigated the use of progressive additional lenses against single vision lenses for myopic progression in children (Gwiazda et al., 2004). It was reported that progressive additional lenses was effective with a reduction in progression of 0.64 D ± 0.21 D over three years on children with larger lags of accommodation, near esophoria, lower myopia at baseline and lesser reading distance. Since high lags of accommodation had been associated with esophoria in myopic children (Goss and Rainey, 1999), the COMET study showed promising results in using progressive additional lenses for the treatment of myopic progression.

Children that participated in the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) study had their accommodative responses measured, and subsequently investigated by Mutti et al. (2002) for the evidence of accommodative lag as either a precursor or following effect of myopia development. It was revealed that high lags of accommodation did not occur just before, but manifested right after myopia development. The authors also found that Asians and children who wore glasses had the highest lags of accommodation after the onset of myopia. A smaller one-year longitudinal study by Weizhong et al. (2008) found no correlation between accommodative lag and myopic progression. The CLEERE investigators subsequently confirmed the findings by Weizhong et al. that accommodative lag was not associated with the ongoing progression of juvenile onset myopia (Berntsen et al., 2011). Although lag of accommodation has been implicated in myopia development due to hyperopic defocus from sustained near work, evidence suggests that increased lag of accommodation is a result, and not a cause, of myopia development. The mild effect seen in the progressive additional lens studies may be attributed to either the reduction of ciliary-choroidal tension by the lenses (Berntsen et al., 2011) or the sectorial reduction of peripheral hyperopic defocus resulting in modest reduction in myopic progression (Smith III et al., 2010).

1.4. Vision-related Quality of Life

The measurement of quality of life complements the assessment of the physical and psychological health, and social functioning (Cella, 1994; Felce and Perry, 1995). Quality of life assessments are multidimensional subjective measurements that evaluate the life of patients in a wide range of areas that include physical, emotional, social well-being, as well as functional and developmental abilities. Quality of life assessments have become an important aspect of clinical subjective assessment of how ocular pathologies affect patients (Guyatt et al., 1993; Muldoon et al., 1998). Patients suffering from visual impairment as a result of ocular diseases such as age-related macular degeneration, retinopathy or glaucoma are likely to experience reductions in their quality of life. Although ametropia can be corrected with spectacles and contact lenses, the quality of life in patients with refractive errors should not be ignored. Myopia can adversely affect the social life of a person, negatively affecting self-esteem, and the choice of profession (Rose et al., 2000). Since myopia affects between 14 % and 33 % of adults (Katz et al., 1997; Vitale et al., 2008) and up to 29 % of children (Saw et al., 2002a), with prevalence rates being much higher in East Asia and Southeast Asian countries (Tay et al., 1992; Lin et al., 2004; He et al., 2009a), it is imperative to investigate the quality of life in patients suffering from refractive errors such as myopia and hyperopia.

Surveys or questionnaires that collect quality of life information of patients are also known as instruments. The acknowledgement of the importance of quality of life information by ophthalmic researchers has resulted in the development of numerous psychometric instruments. Such instruments can either measure the ‘visual function’ or the ‘vision-related quality of life’ (VRQOL). The measurement of ‘visual function’ allows the quantification of the limitation in the daily tasks of a patient caused by the visual impairment. VRQOL is a broader measurement that encompasses the patient’s perception of their living standards, social well-being, health status, concerns, independence and psychological state (The World Health Organisation, 2014). As such, VRQOL should be considered as a more comprehensive measure and a better evaluator of the influence of disease or treatment on vision and the patient’s quality of life, as opposed to purely measuring visual function (Lamoureux and Pesudovs, 2011). The following sections will describe the key instruments used for the measurements of vision-related quality of life.

1.4.1. The Vision and Quality of Life (VisQoL) Instrument

The Vision and Quality of Life (VisQoL) index was developed in response to the lack of a multi-attribute utility model that specifically measures vision-related quality of life (Misajon et al., 2005). The VisQoL is a six-item questionnaire that has been demonstrated to exhibit good psychometric attributes that provides descriptive quality of life outcomes which can also be used to quantify utility values. Chen et al. (2007) used the VisQoL instrument to investigate the difference in quality of life scores between emmetropes, myopes wearing spectacles or contact lenses, and myopes after refractive surgery. The authors simply converted the responses of each item to either positive or negative, giving scores to only negative responses. It was found that myopes wearing contact lenses and spectacles had increased concerns for their safety, coping with daily life, fulfilling their roles, and participating in daily activities, compared to emmetropes or post-refractive surgery myopes. There was a possibility of selection bias where participants were not randomly-selected and surgeons may invite participants who appeared to be satisfied with refractive surgery to participate in the study, potentially resulting in an increase in quality of life scores.

1.4.2. The National Eye Institute Instruments

The National Eye Institute developed the Refractive Error Correction Quality of Life Questionnaire (NEI-RQL) in response to earlier visual functioning questionnaires which were found to be inadequate in differentiating participants with no ocular diseases but only varying degrees of refractive errors (Steinberg et al., 1994; Mangione et al., 2001). The NEI-RQL instrument compares participants with different modes of refractive correction (Berry et al., 2003) and was found to be able to distinguish between different areas of visual function and report differences in outcomes from participants with different degrees of refractive error and refractive correction. The reliability of the NEI-RQL instrument was further confirmed in another report by Hays et al. (2003) where myopes, hyperopes and emmetropes were shown to exhibit statistically significant differences in most of the 13 scales. A limitation of the study was that participants may have been particularly biased towards being either satisfied or dissatisfied with their refractive correction and therefore more keen to participate.

The NEI-RQL 42 item questionnaire was employed in a study that investigated LASIK, orthokeratology, spectacles and contact lens corrections (Queirós et al., 2012). Although all participants were well corrected by the various refractive options, significant differences in the subscales of the instrument were found, providing valuable insights into the differences in vision-related quality of life scores between participants with various modes of correction. It is important to note that Rasch analysis of the NEI-RQL 42 item questionnaire found the subscales to be deficient and that item responses were reported to be incorrectly applied or classified (McAlinden et al., 2011). The Rasch model was constructed based on a logistic model where the response is derived from a linear probabilistic interaction between the ability of the respondent to answer the question and the difficulty of the question (Prieto et al., 2003). Rasch analysis determines if the added scores fits the model and justifies the description of the subject ("What is Rasch Analysis.," 2016). In an Iranian study, however, the NEI-RQL-42 instrument was found to be of high reliability and validity, with Cronbach's α coefficient between 0.74 to 0.92 (Pakpour et al., 2013). Subscale analysis also revealed good homogeneity without significant floor or ceiling effects, contrary to the findings of McAlinden et al. (2011). The differences in findings of the reliability studies could be due to the different methods of analysis, different language of survey, sample size and sample heterogeneity.

A study that investigated the vision-related quality of life in keratoconic patients used the National Eye Institute Visual Functional Questionnaire (NEI-VFQ) and found that the instrument was not sensitive towards detecting differences in refractive error in the one year longitudinal study (Jones-Jordan et al., 2012). As such, the NEI-VFQ may not be as appropriate in monitoring subtle changes in refractive errors.

1.4.3. The Vision Core Measurement 1

The Vision Core Measurement 1 (VCM1) is a 10 item questionnaire that was designed to examine the interaction between vision, psychophysical and social functions (Frost et al., 1998). VCM1 was previously known as VQOL, and was employed by Rose et al. (2000) to evaluate the effect of various degrees of myopia on visual function and quality of life. Together with the Visual Function-14 (VF-14) instrument, it was found that participants with high myopia of worse than -10.00 D had significantly worse scores than low or moderate myopes. There was also no difference in VF-14 and VQOL scores between participants with high myopia and participants with keratoconus. The findings of Rose et al. showed that high myopia can adversely affect a person’s quality of life. As such, practitioners may wish to consider surgical correction for high myopia for the possibility of improving quality of life if the risks do not outweigh the benefits.

The VCM1 questionnaire was used to investigate the vision-related quality of life of 1,683 elderly participants in the United Kingdom, in order to estimate the prevalence of visual impairment (Frost et al., 2001). It was reported that VRQOL-related impairment increased with age, and is higher in lower social classes. While it is possible that there may be recruitment bias due to certain populations being more or less represented than others, this study demonstrates the gravity and extent of visual impairment in the elderly population. The VCM1 instrument was also used to investigate vision impairment in adults born in 1958 (Rahi et al., 2009). Participants with visual impairment (LogMAR visual acuity of 0.3 or worse) had lower vision-related quality of life scores. The authors found significant increases in odds ratio of obtaining a score of two or more, representing ‘more than a little concern about vision’, in participants who have near, distance, unilateral, bilateral, mild, severe and stereo visual impairment. The findings of the research provided insights into the negative impact of lifestyle and work that visual impairment can cause.

The VCM1 instrument was examined for its reliability using Rasch analysis, and was found to fit the Rasch model only after modifications to the categories and response scales (Lamoureux et al., 2008). A subsequent analysis of the VCM1 instrument revealed differential item functioning in some items of the questionnaire (van Nispen et al., 2010). When the questionnaire is taken as a whole, the problem of differential item functioning appears to be minimal. As such, VCM1 is considered to be appropriate for use in community research. However, van Nispen et al. cautioned against the use of VCM1 for the purpose of monitoring treatment.

1.4.4. The Quality of Life Impact of Refractive Correction

The Quality of Life Impact of Refractive Correction (QIRC) questionnaire was specifically designed to measure the impact of spectacle, contact lens, and refractive surgical corrections on VRQOL (Pesudovs et al., 2004). The pilot questionnaire comprises 90 questions, that was subsequently condensed to a 20-question instrument. The QIRC was developed with Rasch analysis and was reported to exhibit high reliability and validity. It addresses the drawback of other Likert instruments that measure VRQOL, where responses are not linear and that questions with varying vision-specific difficulties are awarded the same score.

The QIRC was used to investigate the change in VRQOL after 66 participants had undergone LASIK refractive surgery (Garamendi et al., 2005). It was found that participants had an overall improvement in VRQOL, with women improving more than men, three months after the LASIK surgery. Pesudovs et al. (2006) also found significantly higher VRQOL scores in post-LASIK patients, compared to contact lens and spectacle wearers. Contact lens wearers were also found to exhibit significantly higher VRQOL than spectacle wears, where those with higher magnitudes of refractive error fared worse. The QIRC instrument is a viable instrument that can be used to measure quality of life outcomes with respect to patients' vision, and has been validated to be reliable. However, due to the availability of a variety of VRQOL instruments, the QIRC has not been widely used outside of the developer's research group. As such, more studies by other groups of researchers as well as at other geographical locations would be needed to evaluate the VRQOL between patients with different types of refractive correction using the QIRC.

1.4.5. The Refractive Status and Vision Profile

The development of the Refractive Status and Vision Profile (RSVP) questionnaire was described by Schein (2000), which comprises 42 items, requiring 10 to 15 minutes to complete. The RSVP was piloted on 550 subjects who had a variety of refractive correction including refractive surgery, as well as 176 subjects who were about to undergo refractive surgery. Schein reported very internal Cronbach α internal consistency of between 0.70 and 0.93, and that poorer scores were associated with higher magnitude of refractive error. The RSVP was also deemed to be appropriate in predicting the poor surgical outcomes, where participants exhibited worsening of RSVP scores (Schein et al., 2001). Nichols et al. (2001) conducted a crossover study, where participants were assigned to wear daily or extended wear soft contact lenses. Nichols et al. reported that the participants exhibited better baseline RSVP scores than the baseline scores previously described by Schein (2002). In addition, most of the subscales had no significant differences between having used the contact lenses and the baseline, likely due to the lack of statistical power in 6 out of 8 subscales. This led Nichols et al. to conclude that the RSVP was not suitable in assessing the vision-specific quality of life in contact lens patients.

Garamendi et al. (2006) performed Rasch analysis on the RSVP questionnaire after evaluating the quality of life scores from 91 myopic subjects who had undergone refractive surgery. The authors found the Likert instrument to suffer from ceiling effects, poor usage of response categories, and that the difficulty of the questions had targeted participants' quality of life inadequately. To better determine refractive surgery quality of life outcomes, Garamendi et al. recommended a Rasch converted 20-item RSVP questionnaire with improved consistency and targeting. The RSVP questionnaire is likely to be more suited to survey and monitor patients who are about to or have undergone refractive surgery, and may not be appropriate to evaluate other refractive interventions such as contact lenses. The limited usage of the RSVP in the literature requires further investigations, especially using the Rasch converted version proposed by Garamendi et al.

1.4.6. Time Trade-off and Standard Gamble

Time trade-off is calculated by dividing the number of years of life a participant is willing to sacrifice in return for perfect eyesight and health by the expected remaining years of life of the participant, and subtracting the resultant value from 1. The higher value of time trade-off, the less willing a person is to give up years of his lifespan in exchange for perfect eyesight and health. Standard Gamble on the other hand, is the percentage of risk of blindness (or death) of a hypothetical treatment that the participant is willing to undertake. This hypothetical treatment may either provide perfect eyesight and health, or immediate blindness (or death). Saw et al. (2003) measured these utility values on students between the ages of 15 to 18 years and found better scores in myopes who have better visual acuity and in higher social class. However, there was no difference in utility scores between low, moderate and high myopes. A similar study was conducted on medical students, where utility scores were found to be unusually high (Lim et al., 2005). Medical students who were more likely to opt for refractive surgery had significantly different utility scores compared to those who were unlikely to opt for refractive surgery. It was likely that the medical students had good understanding of myopia which is not life threatening and has minimal health implications. As such, they may not be willing to trade their lifespan or risk death to exchange for perfect eyesight. Therefore, the use of time trade-off and standard gamble seems to be less useful in evaluating myopia in younger people.

1.5. Summary

The increasing prevalence of myopia around the world, particularly in the East and Southeast Asia, underscores the importance of investigating the implications of this pervasive phenomenon. While numerous research studies focused on investigating the cause of myopia development and the treatment options to reduce or prevent the progression of myopia, only a small number of studies have examined the development of and change in refractive errors in young adults, especially in a longitudinal approach. Previous longitudinal studies have shown significant changes in ocular biometry and refraction, and an increase in myopia prevalence, especially when investigating participants exposed to high educational demands (Lin et al., 1996; Kinge and Midelfart, 1999; Kinge et al., 2000; Jorge et al., 2007; Lv and Zhang, 2013). However, there is a possibility that ocular biometric and refractive changes may not be significantly detected in one year (Onal et al., 2007). These studies examined participants who are either undergraduate engineering, medical or optometry students. There has not been any research that examines ocular biometric in addition to refractive changes in Singapore young adults studying in higher education institutions. As such, the present study is the first to examine the change of ocular biometry and manifest subjective refraction in young adults studying in a higher education institution in Singapore.

The assessment of vision-related quality of life (VRQOL) is an important aspect of the well-being of patients, especially as around 81.6 % of young adults (Koh et al., 2014) and 38.9 % of adults over 40 years of age (Gazzard et al., 2013) in Singapore are myopic, requiring refractive correction. Previous studies have examined the VRQOL between myopes, emmetropes with different refractive correction options using various instruments (Rose et al., 2000; Saw et al., 2003; Lim et al., 2005; C. Y. Chen et al., 2007). Saw et al. used time trade-off utility scores to investigate quality of life in medical students in Singapore but yielded inconclusive findings due to the possible unsuitability of the instrument used. With the exception of the study by Saw et al., no other studies has examined the VRQOL in Singapore young adults studying in a higher education institution. As such, this study is also the first to employ the NEI-RQL-42 instrument to investigate the differences in VRQOL between young adult participants with different refractive status, as well as with different types of refractive corrections.

The aims of this research presented in this thesis were to:

- describe the demographics, refractive status, ocular biometric parameters, as well as factors that may influence myopia in Singapore young adults;
- examine the relationships between refractive error and ocular biometric parameters and their 2-year longitudinal changes in Singapore young adults; and
- identify the differences in VRQOL between various myopia and refractive correction groups, and describe the 2-year longitudinal changes in VRQOL in Singapore young adults.

Chapter 2: Method

This chapter describes the methods that encompassed the entire programme of research, incorporating the data collection and data analytical procedures during the baseline, 12 month visit, and the 24 month visit.

2.1. Study Design and Participant Recruitment

This study was reviewed and approved by the Aston University Research Ethics Committee (AU REC) and the Ngee Ann Polytechnic Institutional Review Board (NP-IRB) (see Appendix 1). The research protocol of this study adhered to the tenets of the Declaration of Helsinki. This is the first study of a longitudinal design to investigate the potential change in ocular biometry and refraction, as well as to examine the vision-related quality of life in young adults. Lv and Zhang (2013) had found significant refraction changes in Chinese medical students over a period of two years, while Onal et al. (2007) reported no change in refraction in a period of only one year. As such, a two-year follow-up period would be a viable duration to examine for longitudinal changes in refraction and biometry in a sample that is of the same ethnicity to the study by Lv and Zhang (2013). There were no interventions given to participants in this study. The study was conducted at Ngee Ann Polytechnic, a tertiary educational institution that admits secondary school graduates into three-year diploma courses.

The sample size of at least 99 participants that allow for comparisons between three groups of participants was calculated with G*Power (version 3.0.10, Franz Faul, Universität Kiel, Germany), with a significance level of $\alpha = 0.05$, power of 0.80, and an effect size of 0.30. The number of participants that were to be recruited was rounded off to 100 where the longitudinal analysis over a period of two years using paired T-test using was calculated to require a minimum effect size of 0.28, with the significance level of $\alpha = 0.05$, and power of 0.80. Participants were recruited by non-probabilistic direct contact and referral sampling from the student pool of Ngee Ann Polytechnic. To recruit participants, a poster was put up on the notice board at the Ngee Ann Polytechnic Optometry Centre (NPOC). Students who presented at NPOC for an eye examination were invited to participate in the study. Advertisements were also made available on social media (Facebook, Menlo Park, California, United States) groups that were specific to the student pool of the polytechnic to invite potential participants.

Prospective participants were provided with the Patient Information Sheet (see Appendix 2) and were informed of the purpose, procedures, duration of the study, and that they would be asked to return for a 12 and 24 month follow-up visit. All prospective participants were assured that their participation was entirely voluntary in nature, and that they were free to withdraw their participation at any point, even after providing their informed consent. Prospective participants who indicated their interest in participating in the study provided informed consent using the consent form (see Appendix 3). Participants who were below the age of 21 years at the time of recruitment were asked to provide parental consent prior to any data collection, which was a requirement by the NP-IRB. No data were collected for any participants prior to the provision of informed consent. Participants were informed that the durations for the baseline visit as well as the subsequent follow-up visits were approximately 30 to 45 minutes each.

2.2. Recruitment, Criteria and Eligibility

Participants with any history of ocular diseases, refractive surgery, or systemic diseases that could potentially affect refraction, ocular biometry, or visual acuity were excluded from the study. Participants who had not undergone an optometric examination within the past year were given an ocular examination by the investigator to determine the health status of both eyes. Anterior ocular health was examined using a slit lamp biomicroscope (Topcon Corp., Tokyo, Japan). Posterior ocular health was examined by performing fundus photography using the Topcon TRC-NW8 (Topcon Corp., Tokyo, Japan). Non-contact tonometry was performed with the Reichert 7CR Auto Tonometer (Reichert Inc., New York, United States). Participants were also required to have best spectacle corrected visual acuities of 6/9 or better in each eye to participate in this study. A total of 100 healthy participants were initially recruited. However, one participant was excluded due to amblyopia of the left eye. The baseline visits took place between September 2014 and December 2014.

2.3. Procedures Performed for Each Visit

The procedures that were performed on each participant are shown in Table 2.1. The bespoke questionnaire for the baseline visit was different from the 12 month and 24 month follow-up visits, where there were questions on the participants' demographic profile and the age of first use of refractive correction. All other procedures were the same for all three visits, with the exception of accommodative response. The Grand Seiko WAM-5500 Binocular Auto-refractor / Keratometer (Grand Seiko Co., Fukuyama City, Hiroshima, Japan) malfunctioned at the start of the 24 month visit period. As such, accommodative response data were not collected for all participants at the 24 month visit.

	Baseline	12 Month Visit	24 Month Visit
Bespoke Questionnaire	✓	✓	✓
• Demographics	✓		
• Age of Initial Correction	✓		
• Percentage of Eyewear Use	✓	✓	✓
• Duration of Near Work, Sports, Outdoor Activities	✓	✓	✓
• Parental Myopia	✓	✓	✓
• Academic Scores	✓	✓	✓
NEI-RQL-42 Questionnaire	✓	✓	✓
Subjective Refraction	✓	✓	✓
Ocular Biometry	✓	✓	✓
Accommodative Response	✓	✓	

Table 2.1 Procedures performed during the baseline, 12 month visit, and the 24 month visit.

2.4. Subjective Refraction

Subjective manifest refraction was performed for all participants to obtain the spectacle prescription associated with the best corrected visual acuity for each eye. Cycloplegic refraction was not performed as there was no provision in the existing laws for optometrists to use diagnostic pharmaceutical agents in Singapore ("Singapore Statutes Online - 213A - Optometrists and Opticians Act," 2008). Despite the inability to perform cycloplegic refraction, it is considered reasonable to perform subjective refraction for this group of participants as they were at least 16 years of age and were unlikely to over-accommodate during the refraction process (Beers and Van der Heijde, 1996). To obtain the approximate refraction to commence subjective refraction, the participant's spectacles were measured using an automated focimeter (Huvitz HLM-7000, Huvitz Co. Ltd., Gyeonggi-do, Korea). If the participant was not a spectacle wearer, automated refraction was performed using the Topcon TRK-1P Auto-Kerato-Refracto-Tonometer (Topcon Corp., Tokyo, Japan) to obtain the objective refraction findings.

Subjective refraction was performed with the Topcon VT-10 phoropter (Topcon Corp., Tokyo, Japan) if the spherical power of measured refraction from either focimetry or autorefraction was found to be no worse than -6.00 D in either eye. The trial frame and lenses were used if the estimated refraction was observed to be worse than -6.00 D. The rationale of not using the phoropter for higher prescriptions was that it would result in a higher vertex distance, artificially inducing more negative refraction findings. The right eye for each participant was refracted first, with the left eye occluded using a standard occluder from the trial lens set, or the occluder in the phoropter, depending on which was used. The spherical power was refined first, until there was no improvement in reading the next smaller line of letters, with the most positive and least negative lens. The cylinder axis and power was determined using either a handheld ±0.25 D Jackson cross cylinder when refracting with a trial frame, or the Jackson cross cylinder in the phoropter. The spherical power was refined again, where the endpoint was determined by the spherical lens that provided the least minus and maximum plus refraction with the most improved visual acuity. Upon completion of the subjective refraction of the right eye, the right eye was occluded and the same refraction procedures were performed for the left eye. The best spectacle corrected visual acuity was obtained with an illuminated LogMAR chart (Precision Vision, Laselle, Illinois, United States) at four metres for each eye. Due to the unavailability of the LogMAR chart during the 12 and 24 month follow-up visits, the Snellen chart from the overhead projector was used to obtain the best spectacle corrected visual acuity.

Without the use of cycloplegic pharmaceutical agents, subjective refraction is the next best appropriate method to obtain refraction findings. Elliott et al. (1997) found subjective refraction to be the most repeatable method of measuring refraction, compared to two types of auto-refractors. Rosenfield and Chiu (1995) examined the subjective and objective refraction that was performed for 12 subjects on 5 different occasions by a single masked examiner, and reported the 95 % limits of agreement for subjective and objective refraction to be within ±0.27 D and ±0.31 D respectively. However, when more than one examiner performs subjective refraction on the same subject, the refraction results are likely to be less reproducible than automated refraction, with 95 % limits of agreement between -1.38 D to +0.65 D (Bullimore et al., 1998; MacKenzie, 2008). In the present study, all subjective refractions were performed by the sole investigator, which would ensure repeatability, avoiding poor reproducibility when multiple examiners are involved. Leinonen et al. (2006) investigated the refraction measurements of three groups of subjects - heathy eyes, pseudophakic, and cataractous. The authors found reduced repeatability in those with poorer best corrected visual acuity. In the present study, the best corrected visual acuity of all participants was at least 6/9, which ensured higher repeatability of refraction findings by the same examiner.

2.5. Ocular Biometry

Ocular biometry measurements were performed for all participants using the Lenstar LS900 (Haag Streit AG, Koeniz, Switzerland), which was calibrated at least once a week, upon prompting by the software. When performing ocular biometry measurements with the Lenstar LS900, the participant was instructed to rest his or her chin firmly on the chinrest, with the forehead resting on the forehead rest, to ensure accuracy of the measurements. To commence measurements, the Lenstar device was positioned in line with the participant’s right eye. The participant was instructed to fixate on the orange light and to blink freely. The device was aligned appropriately in accordance to the sharpness of the mires reflected off the cornea. The trigger button was then pushed to enter the measurement mode. To obtain a measurement, the Lenstar device had to be positioned to ensure the sharpness of the central reflection light. The participant was then instructed to refrain from blinking. The trigger button was pushed again to obtain the measurement, which takes approximately three to six seconds. Five ocular biometric measurements were obtained for the right eye of each participant, which could be completed within one minute. The measurements were repeated if the standard deviations of the five measurements were outside the acceptable range, as determined the software. The measurements obtained included the corneal thickness, anterior chamber depth, crystalline lens thickness, axial length, corneal diameter, pupil diameter, and keratometry. Ocular biometry measurements were performed on the right eye for all participants.

2.6. Bespoke Questionnaire

A bespoke questionnaire (see Appendix 4) was completed by each participant to obtain demographic data and information on the participant’s ocular and refractive status. Demographic data including gender, month and year of birth, and ethnicity were obtained during the baseline visit. As participants were students of Ngee Ann Polytechnic, the participants were required to fill in the year of study, as well as the course of study. Participants were also asked the age of initial refractive correction during the baseline visit. This information was used as a surrogate for the age of myopia onset.

2.6.1. Refractive Correction Usage

To determine the usage preference and dependence on refractive correction, each participant was asked to provide the percentage of time for spectacle and contact lens wear, as well as the percentage of time that refractive correction was not worn. The participants were informed that the percentages of spectacles wear, contact lens wear, and non-usage of refractive correction only applied to all waking hours, and that they had to add up to 100 %. Participants who used spectacles at least 55 % of the time were grouped as Spectacle-Wearers, while participants who did not use any refractive correction for at least 55 % of the time were grouped as Non-Wearers. The remaining participants were grouped as Contact Lens Mixed-Wearers (CLM-Wearers). CLM-Wearers were not major spectacles users (less than 55 % of the time) and used refractive correction for more the 55 % of the time. The participants were grouped by using 55 % to identify the major refractive correction used by each participant, where the minority refractive corrections would never be more than 45 %.

2.6.2. Near Work, Dioptre-Hour, and Outdoor Activities

A table was provided in the questionnaire to allow participants to input the number of hours spent reading, using electronic gadgets, playing computer games, watching television, doing outdoor activities and playing sports on an average weekday, as well as on an average weekend day (see Appendix 4). The amount of time spent on reading in a week was calculated by multiplying the total number of hours spent reading on a weekday by 5, and adding the amount of time spent reading on a weekend day by 2. The same calculation was performed for time spent on computer usage, television, outdoor activities, outdoor sports, and all sport activities. The Dioptre-Hour was calculated by obtaining the sum of the time spent on reading multiplied by 3, the time spent using the computer multiplied by 2, and the time spent watching television, which was described by Mutti et al. (2002) and Saw et al. (2006). The rationale of calculating the Dioptre-Hour was to include the accommodative effort towards quantifying near work, in addition to time spent. The information obtained in this section would allow the analysis of the interaction between near work, outdoor activities and myopic changes as near work has been implicated in causing myopia progression (Ashton, 1985; Saw et al., 2001a; Ip et al., 2008). In addition, outdoor activities have been reported to have a protective effect on myopia progression (Dirani et al., 2009; Lu et al., 2009; Guo et al., 2013).

2.6.3. Parental Myopia and Academic Achievements

As parental myopia increases the odds of having myopia (Mutti et al., 2002; Ip et al., 2007; Morgan and Rose, 2009), the questionnaire attempted to identify the refractive errors of the parents. The participants were asked if his or her biological father and mother had difficulty seeing at distance or near, and whether they used spectacles for near-sightedness (myopia), far-sightedness (hyperopia), or having trouble reading (presbyopia). Participants who were unsure of the refractive status of either parent were not considered for analysis. Each participant also had to provide their Primary School Leaving Examinations (PSLE) aggregate, General Certificate of Education (GCE) 'O' Levels aggregate, as well as their recent and cumulative Grade Point Average (GPA) at the polytechnic. The PSLE is a national examination that is taken by all primary school students at the end of their six-year primary school education. The PSLE score is a determinant of the eligibility to enter secondary schools. The GCE 'O' Levels aggregate is obtained after the GCE 'O' Level national examinations, which is used for the entry into post-secondary tertiary institutions such as junior colleges and polytechnics. Each participant's academic results would provide insights into their academic abilities where analysis with their myopic status were performed.

2.7. Vision-related Quality of Life

2.7.1. NEI-RQL-42 Questionnaire

The National Eye Institute Refractive Error Correction Quality of Life (NEI-RQL-42) instrument (see Appendix 5) queries the visual experience and the physical wellbeing of the respondent in a given scenario. The questionnaire was completed by each participant to obtain vision-related quality of life (VRQOL) data. Previous studies that employed the NEI RQL-42 instrument had obtained significant differences in VRQOL scores between participants with different refractive corrections (Berry et al., 2003; Hays et al., 2003;

Queirós et al., 2012). Participants were asked to complete the questionnaire by themselves, and to read the questions very carefully as some questions may appear to be similar but are actually quite different. Each participant was asked to mark a cross on the response that best matched his or her circumstances. If the participant was unsure, he or she was asked to provide the response that was the closest match and to make a comment next to the question. There are 42 questions in total, where response options ranged from two to six. The response for each question was scored with the aid of a scoring manual (see Appendix 6), where the response that denotes the best quality of life was given the highest possible score of 100, and the response that denotes the worst quality of life was given a score of zero. The calculated score for each question thus represents the attained percentage out of the best possible score of 100. The score for each question was averaged with the score for other questions that belong in the same subscale to obtain the average score for each of the 13 subscales. The raw score obtained from each set of completed questionnaire was entered into a Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, Washington, United States) that was programmed to automatically calculate the score of each question in accordance to the manual. To obtain the score for each subscale, the spreadsheet was also programmed to automatically obtain the average scores of the questions that were from the same subscale. A global score was also calculated by obtaining the average score of all 42 questions.

2.7.2. NEI-RQL-42 Subscales

The 13 subscales of the NEI-RQL-42 questionnaire include Clarity of Vision, Expectations, Near Vision, Far Vision, Diurnal Fluctuations, Activity Limitations, Glare, Symptoms, Dependence on Correction, Worry, Suboptimal Correction, Appearance and Overall Satisfaction with Correction. The questions in the Clarity of Vision subscale asked about the clarity of vision experienced by the participant, as well as whether the participant experienced distorted vision, blurry vision, or having trouble seeing. The Expectations subscale asked for the difference or the change in life if the participant were to have perfect vision. For the Near Vision subscale, four questions surveyed the difficulties in performing close work and daily activities such as sewing, cooking, and reading newspapers. The Far Vision subscale surveyed the level of difficulties faced by the participant in situations such as judging distances, seeing approaching cars and people, getting used to dark environments, as well as driving at night and in difficult road conditions. For the Diurnal Fluctuation subscale, the participant was asked about the difficulties faced due to changes in the clarity of vision throughout the day, and whether the participant was bothered by such changes. Under Activity Limitations, four questions asked about the difficulties faced by the participant when participating in outdoor activities, whether the participant’s vision limited such activities, and if there were any activities that the participant did not do and wished to do because of his or her vision or visual correction. Under Glare, participants were asked if they experienced and were bothered by glare, starbursts and/or haloes.

In the Symptoms subscale, participants were surveyed on the frequency and severity of ocular pain or discomfort, the severity of dryness, the frequency of headaches, as well as whether they experienced tearing, itching and soreness or tiredness. The Dependence on Correction subscale asked about the necessity of using vision corrections for reading and driving. Participants were asked about how often they worry and think about their vision under the Worry subscale. In the Suboptimal subscale, the participant was asked if there was any use of vision correction that was uncomfortable and worse in performance than another correction in the past four weeks. For the appearance subscale, three questions surveyed the participants on the satisfaction of their vision correction based on their appearance. Finally, for the Satisfaction with Correction subscale, one question surveyed on the participants’ overall satisfaction with their present vision correction.

2.8. Baseline Accommodative Response

The Grand Seiko WAM-5500 Binocular Auto-refractor / Keratometer (Grand Seiko Co., Fukuyama City, Hiroshima, Japan) was used to determine each participant's static accommodative responses in the right eye to various accommodative stimuli (Figure 2.1). A Badal lens system was set up using a +5.00 D spherical lens to effectively reduce the distance required for the presentation of the accommodative stimuli. The Badal lens was positioned 20 cm from the nodal point of the eye. Objective auto-refraction was first measured for each participant using the 0 D accommodative stimulus, where a reading chart would be positioned 20 cm from the Badal lens. The participant was instructed to focus at the letters that were presented when viewing through the centre of the Badal lens, and to maintain clarity of the letters at all times. Five measurements were taken with the participant using their habitual correction, which may be spectacles, contact lenses or none. The habitual correction would continue to be used for the other accommodative stimuli only if the average of the spherical equivalent of five refraction measurements were within ±0.50 D. If the average refraction measurement using the habitual correction was outside ±0.50 D, the subjective refraction findings obtained earlier would be used with trial frame and lenses.

Objective auto-refraction was performed with accommodative stimuli of 1 D, 2 D, 3 D, and 4 D, where the effective accommodation of each participant was calculated for each accommodative stimulus. The formula used to calculate the effective accommodative demand was as follows:

$$\frac{-(a \cdot F) - 1}{(VD \cdot Rx - 1)\left(a - VD\left(a \cdot F + Rx\left(a - d(a \cdot F + 1)\right) + 1\right) - d(a \cdot F + 1)\right)}$$

From the above formula, a is the distance between the Badal lens and the near chart; F is the power of the Badal lens (+5.00 D), VD is the vertex distance between the spectacle plane and the eye, Rx is the best corrected distance spectacle refraction, and d is the distance between the Badal lens and the spectacle plane. Subsequently, the compensated distance of the Badal lens to the reading chart was calculated, and the reading chart repositioned to correct for the change in effective accommodation caused by the vertex distance of the participant's spectacles or trial frame and the spectacle / trial lens power.

When five measurements were obtained for each accommodative stimulus, the spherical equivalent of the highest reading had to be no greater than 0.50 D from the lowest reading. The averaged reading of each set of five measurements was recorded as the accommodative response for each stimulus. Static sampling was used instead of dynamic measurements as it is less technically challenging to manually capture five consistent readings where the readings can be captured between blinks. Dynamic measurements were not favoured in this setup as measurements may get interrupted with blinks or with subtle misalignments, especially when ophthalmic and trial lenses were used to stimulate accommodation. In addition, the WAM-5500 device samples refraction at a frequency of only 4 Hz in the dynamic mode, which would add little value compared to using the static mode.

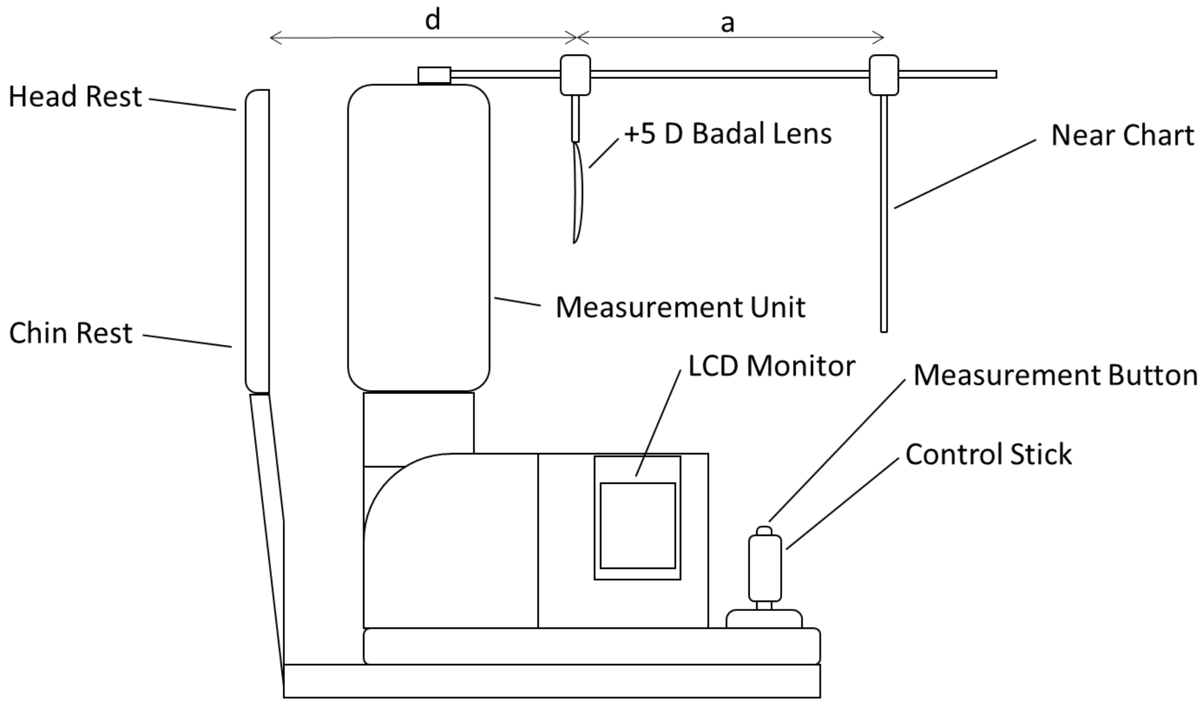

Figure 2.1. Schematic image of the Grand Seiko WAM-5500 Binocular Accommodation Auto-Ref / Keratometer set-up with a +5.00 D badal lens system. The distance between the eye's nodal point to the Badal lens (d) is 20 cm. The distance from the Badal lens to the near chart (a) is varied to adjust the accommodation stimulus by moving the near chart.

2.9. 12 and 24 Month Follow-up Visits

Participants were required to attend three visits over a two-year period for this longitudinal study. A two-year period was necessary in order to effectively analyse the ocular biometric changes as it would be difficult to demonstrate any significant changes over a one-year period. The 12 month visit for all participants occurred from September 2014 to January 2015, and the 24 month visit occurred from September 2015 to January 2016. During the follow-up visits, participants completed a bespoke questionnaire that asked the percentage of spectacles usage, contact lens usage, and non-usage of vision correction for a typical day during non-sleeping hours. The participants were also asked to report the duration of near-work, computer and electronic gadgets usage (e.g. mobile phone / tablet PC / e-reader, etc.), outdoor and indoor sports and activities in a typical week day, as well as a typical weekend day. The NEI-RQL-42 questionnaire was also completed by each participant. Manifest subjective refraction was performed for each participant with the same techniques as the baseline examination. Ocular biometry was performed using the Lenstar LS900 to obtain the corneal thickness, anterior chamber depth, crystalline lens thickness, axial length and keratometry. Objective auto-refraction was performed using the Grand Seiko WAM-5500 Auto-refractometer / Keratometer to determine the accommodative responses for 0 D, 1 D, 2 D, 3 D, and 4 D accommodative stimuli. During the 12 month visit, the 1 D, 2 D, 3 D, and 4 D accommodative stimuli were randomly presented. The Grand Seiko WAM-5500 malfunctioned and was unavailable for usage throughout most of the period when the 24 month follow-up visits were taking place. As such, accommodative response findings are unavailable for the 24 month follow-up visits. The duration for each follow-up visit was approximately 30 minutes.

2.10. Statistical Analysis

Data collected was entered into Microsoft Excel (Microsoft Corporation, Redmond, Washington, United States) for collation. The data was subsequently transferred to SPSS Statistics 23 (IBM, Armonk, North Castle, New York, United States) for analysis. The normality of each data set was examined by to determine if parametric or non-parametric tests were to be used. For statistical analysis that compared between independent groups, the Shapiro-Wilk test was performed, where the significance value of less than 0.05 would determine that the data for each group was not normal. In addition, the skew and kurtosis was examined to aid in the determination of data normality, where values of lesser than -1.0 and greater than 1.0 would suggest non-normality. The Mann Whitney U test and the Kruskal Wallis test were used to compare between two independent groups and three independent groups, respectively, as the data was determined to be not normally distributed. For related samples, the Shapiro-Wilk test, aided by the information on the skew and kurtosis, was performed on the difference between the two related sets of data. As the data was determined to be not normally distributed, the Wilcoxon Signed Rank test and the Friedman test was used when determining the changes in two and three related samples, respectively.

The demographics of the sample were analysed, where the number of male and female participants, age range and ethnic groups were reported. The distributions of refractive error were also reported, where hyperopia was defined as spherical equivalent (SE) refractive error of +0.50 D or higher and myopia was defined as SE -0.50 D or lesser. Emmetropia was defined as lesser than SE +0.50 D, and greater than SE -0.50 D. The participants were also grouped as Non-Myopes (SE < -0.50 D), Low-Myopes (SE from -0.50 D to < -3.00 D), and Mod/High-Myopes (SE -3.00 or worse). Due to the lower number of recruited high myopes, moderate and high myopes were grouped together to allow for a higher sample size that is comparable to Low-Myopes. The ocular biometry parameters, accommodative error index, and PSLE examination scores were compared between Non-Myopes, Low-Myopes, and Mod/High-Myopes. The spherical equivalent refraction and ocular biometric parameters were compared between participants with no myopic parents and participants with at least one myopic parent. Correlation analyses were performed to examine the relationship between the age of myopia onset, and the spherical equivalent refractive error, as well as the ocular biometric parameters. The interpretation of the strength of linear relationships between variables was adopted from the articles by Chan (2003) and Mukaka (2012) (Table 2.2).

The changes in refraction and ocular biometric parameters over the course of 24 months were examined between and within the refractive error groups. Multiple regression analyses were performed to determine the most significant parameter that influenced refractive error and the change in ocular parameters over time. The VRQOL scores for each subscale were compared between Non-Myopes, Low-Myopes and Mod/High-

Myopes and also between Spectacle-Wearers, Contact Lens Mixed-Wearers (CLM-Wearers), and Non-Wearers. The differences in the VRQOL subscale scores between the baseline, the 12 month visit, and the 24 month visits were also described.

<table>
<tr><th colspan="2">Chan (2003)</th><th colspan="2">Mukaka (2012)</th><th colspan="2">Present Study</th></tr>
<tr><td>r</td><td>Strength</td><td>r</td><td>Strength</td><td>r</td><td>Strength</td></tr>
<tr><td rowspan="2">≥ 0.8</td><td rowspan="2">Very Strong</td><td>0.90 to 1.00</td><td>Very High</td><td>≥ 0.90</td><td>Very Strong</td></tr>
<tr><td>0.70 to 0.90</td><td>High</td><td>0.70 to 0.89</td><td>Strong</td></tr>
<tr><td>0.6 to 0.8</td><td>Moderately Strong</td><td>0.50 to 0.70</td><td>Moderate</td><td>0.50 to 0.69</td><td>Moderate</td></tr>
<tr><td>0.3 to 0.5</td><td>Fair</td><td>0.30 to 0.50</td><td>Low</td><td>0.30 to 0.49</td><td>Low</td></tr>
<tr><td>< 0.30</td><td>Poor</td><td>0.00 to 0.30</td><td>Negligible</td><td>< 0.30</td><td>Poor</td></tr>
</table>

Table 2.2 Interpretation of correlation coefficients (r) according to the articles by Chan (2003) and Mukaka (2012), as well as the adopted interpretation for this study.

Chapter 3: Refractive Error, Ocular Biometry, Corrections, in Singapore Young Adults in Tertiary Education

This chapter sets out to examine the prevalence of myopia, hyperopia, and to report the percentage of emmetropes amongst the participants. The ocular biometric parameters will also be reported to establish the cross-sectional data of corneal thickness, corneal radius, anterior chamber depth, lens thickness, vitreous chamber depth axial length, and the axial length / corneal radius ratio. The usage pattern of spectacles, contact lenses, as well as non-usage of eye wear will also be reported. Important factors that may influence myopia, including age of initial refractive correction, near work, outdoor activities, accommodative responses, parental myopia, and academic achievement, will be presented. There has yet to be any previous reports of the ocular biometric parameters in addition to refraction findings on Singapore young adults studying in a pre-university tertiary education. As such, the data presented in this chapter will provide insight on the ocular status of this unique sample of participants.

3.1. Results

3.1.1. Demographic of Participants

The data collected from the baseline visit of this longitudinal study will be presented in this chapter. A total of 100 participants were recruited, with 99 participants included for statistical analysis. One participant was excluded from analysis due to amblyopia of the left eye. All participants were full time students of Ngee Ann Polytechnic at the time of recruitment. There were 70 (70.7 %) female participants and 29 (29.3 %) male participants. The mean age of the participants at the point of baseline data collection was 18.1 ± 1.1 years, ranging from 16 to 22 years (Figure 1). The majority of participants were Chinese in ethnicity (89.9 %). Participants of Malay and Indian ethnicity comprised 4 % and 3 % of the cohort, respectively. Two (2.0 %) participants had mixed heritage of Chinese and Malay, while one (1.0 %) participant was Burmese. Due to the non-probabilistic direct contact and referral sampling nature of this study, 84 (84.5 %) of participants were optometry students, and 15 (15.2 %) participants were studying other courses in the institution. There were 32 (32.3 %) participants in the first year of study, 45 (45.5 %) students in the second year of study, and 20 (20.2 %) participants in the third year of study. There were also two participants in the fourth and fifth year of study, as a result of repeating failed modules.

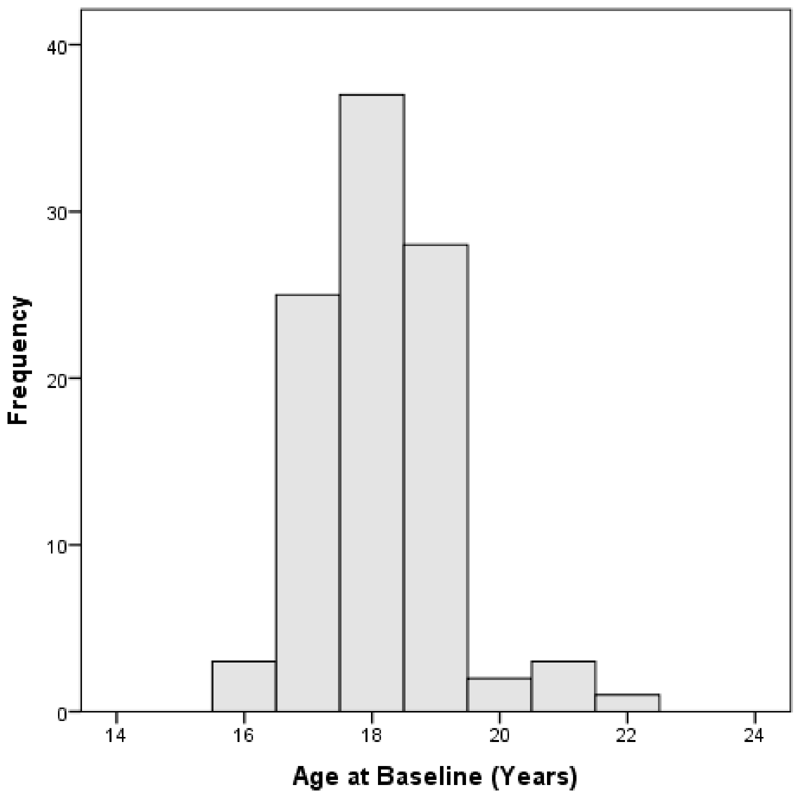

Figure 3.1 Frequency diagram of participants' age at baseline

3.1.2. Refractive Error

The mean spherical power obtained from subjective refraction was -2.68 ± 2.32 D, ranging from -9.00 D to +0.75 D for the right eye, and -2.57 ± 2.30 D, ranging from -12.00 D to +0.75 D for the left eye. The mean cylindrical power for the right eye was -0.68 ± 0.63 D, ranging from -3.00 D to +0.00 D, and -0.72 ± 0.66 D, ranging from -3.25 D to +0.00 D for the left eye. The mean spherical equivalent was -3.02 ± 2.46 D, ranging from -9.88 D to

+0.63 for the right eye, and -2.93 ± 2.45 D, ranging from -12.88 D to +0.63 D for the left eye. No significant differences were found between right and left eyes for the spherical (Z = -1.885, p = 0.059), cylindrical (Z = -1.342, p = 0.179) and spherical equivalent powers (Z = -1.890, p = 0.059) with the Wilcoxon Signed Rank test (Table 3.1).

For the right eye of all participants, 86 (86.9 %) were myopic, 2 (2.0 %) were hyperopic and 11 (11.1 %) were emmetropic. For the left eye of all participants, 82 (82.8 %) participants were myopic, 3 (3 %) participants were hyperopic and 14 (14.1 %) participants were emmetropic. When comparing between male and female gender, no significant differences were found for the sphere, cylinder, and spherical equivalent power of each eye (Table 3.2). When participants were grouped according to the eye with the lower magnitude of refractive error, 18 (18.2 %) were grouped under Non-Myopes (≥ -0.49 D), 40 (40.4 %) were grouped under Low-Myopes (-0.50 D to -2.99 D), and 41 (41.4 %) were grouped under Mod/High-Myopes (≤ -3.00 D) (Table 3.3). Such grouping facilitates the analysis of vision-related quality of life in Chapter 5, as participants would likely report their visual experience based on the better eye, especially if they rely lesser on refractive correction due to the better eye. When participants were grouped according to the spherical equivalent refractive error of the right eye, 13 (11.3 %) were Non-Myopes, 39 (33.9 %) were Low-Myopes, and 47 (86.1 %) were Mod/High-Myopes (Table 3.4).

	Right Eye	**Left Eye**	**Sig.**
Sphere	-2.68 ± 2.32 D	-2.57 ± 2.30 D	p = 0.059
Cylinder	-0.68 ± 0.63 D	-0.72 ± 0.66 D	p = 0.179
Spherical Equivalent	-3.02 ± 2.46 D	-2.93 ± 2.45 D	p = 0.059

Table 3.1 Mean refraction (mean ± standard deviation) for right and left eyes. There were no significant differences between the right and left eye for sphere, cylinder, and spherical equivalents (n = 99).

	Females (n = 70)	**Males** (n = 29)	**Sig.**
Right Sphere	-2.75 ± 2.23	-2.51 ± 2.56	p = 0.464
Right Cylinder	-0.66 ± 0.65	-0.75 ± 0.57	p = 0.188
Right MSE	-3.08 ± 2.36	-2.89 ± 2.72	p = 0.501
Left Sphere	-2.55 ± 2.37	-2.62 ± 2.16	p = 0.805
Left Cylinder	-0.70 ± 0.62	-0.78 ± 0.76	p = 0.861
Left MSE	-2.90 ± 2.50	-3.01 ± 2.36	p = 0.726

Table 3.2 Mean spherical equivalent refraction (mean ± standard deviation*)* between females and males. There were no significant differences between females and males for any refraction components (n = 99).

	Non-Myopes (n = 18)	**Low-Myopes** (n = 40)	**Mod/High-Myopes** (n = 41)
Right Eye MSE	-0.147 ± 0.50	-1.99 ± 0.99	-5.29 ± 1.92
Left Eye MSE	+0.00 ± 0.348	-2.03 ± 0.98	-5.10 ± 2.05

Table 3.3 Mean spherical equivalent refraction (mean ± standard deviation) when grouped by the eye with the lower magnitude of refractive error (n = 99).

	Non-Myopes (n = 13)	**Low-Myopes** (n = 39)	**Mod/High-Myopes** (n = 47)
Right Eye MSE	0.15 ± 0.28	-1.66 ± 0.87	-5.03 ± 1.92

Table 3.4 Mean spherical equivalent refraction (mean ± standard deviation) when grouped by the refractive error of the right eye (n = 99).

3.1.3. Refractive Correction

When all participants were surveyed on the percentage of the time during all waking hours for the usage and non-usage of refractive corrections, 20 (20.2 %) participants reported not using spectacles at all, 12 (12.1 %) participants reported using spectacles all the time, while 50 (50.5 %) participants reported using spectacles at least 55 % of the time (Table 3.5). For contact lens wear, 40 (40.4 %) participants did not use contact lenses at all, none of the participants used contact lenses at all times, and 11 (11.1 %) participants used contact lenses at least 55 % of the time. Forty (40.4 %) participants had some form of correction at any point of time, while 17 (17.2 %) participants did not use any form of refractive correction at all times. There were also 30 (30.3 %) participants who did not use any form of refractive correction for at least 55 % of the time.

Eighty-two (82.8 %) participants reported the need to use refractive correction to correct their ametropia, and 17 (17.2 %) participants did not use any form of refractive correction at all. Amongst the 82 participants who used refractive correction, 3 (3.7 %) participants did not use spectacles at all, 12 (14.6 %) participants used spectacles all the time, and 50 (61.0 %) participants used spectacles at least 55 % of the time (Table 3.6). Regarding contact lens wear, 23 (28.0 %) participants did not use contact lenses at all, none of the participants used contact lenses all the time, and 11 (13.4 %) participants used contact lenses at least 55 % of the time. Of the 82 participants who needed to use refractive correction at any time, 40 (48.8 %) participants reported needing to use refractive correction at all times. Thirteen (15.9 %) participants reported not using any correction at least 55 % of the time.

	0 % of the time	**100 % of the time**	**≥ 55 % of the time**
Spectacles	20.2 %	12.1 %	50.5 %
Contact Lenses	40.4 %	0.0 %	11.1 %
No Correction	40.4 %	17.2 %	30.3 %

Table 3.5 Duration of usage and non-usage of refractive corrections for all participants (n = 99).

	0 % of the time	100 % of the time	≥ 55 % of the time
Spectacles	3.7 %	14.6 %	61.0 %
Contact Lenses	28.0 %	0.0 %	13.4 %
No Correction	48.8 %	0.0 %	15.9 %

Table 3.6 Duration of usage and non-usage of refractive corrections for participants who require refractive correction (n = 82).

3.1.4. Ocular Biometry

Ocular biometric measurements were performed for the right eye of all participants using the Lenstar LS 900. The mean central corneal thickness was 563.37 ± 32.81 µm, and ranged from 481 to 648 µm. Anterior chamber depth measurements ranged from 2.24 mm to 4.05 mm, with a mean of 3.07 ± 0.26 mm. Crystalline lens thickness ranged from 3.13 mm to 4.15 mm, with a mean of 3.54 mm. The mean axial length was 24.68 ± 1.21, and ranged from 22.03 mm to 28.31 mm. Vitreous chamber depth ranged from 14.92 mm to 20.57 mm, with a mean of 17.51 ± 1.16 mm. The distributions of the corneal thickness, lens thickness, axial length, and vitreous chamber depth were normal (Shapiro-Wilk, $p > 0.05$). The distribution of the anterior chamber depth measurements was not of a normal distribution due to leptokurtosis (Shapiro-Wilk, $p = 0.035$). However, the non-parametric Mann-Whitney U test was used to compare the ocular parameters due to the much smaller sample size of males (n = 29) compared to females (n = 70). Although there were no differences in refraction between males and females, significant differences were found between the gender groups for anterior chamber depth ($Z = 2.538$, $p = 0.011$), axial length ($Z = -2.541$, $p = 0.011$), vitreous chamber depth ($Z = -2.318$, $p = 0.020$), and corneal radius ($Z = -3.384$, $p = 0.001$) (Table 3.7).

	Females (n = 70)	Males (n = 29)	Sig.
Corneal Thickness	562.40 ± 32.4	565.72 ± 34.15	p = 0.470
Anterior Chamber Depth	3.03 ± 0.23	3.18 ± 0.29	p = 0.011*
Lens thickness	3.56 ± 0.20	3.49 ± 0.13	p = 0.149
Axial Length	24.44 ± 1.07	25.25 ± 1.35	p = 0.011*
Vitreous Chamber Depth	17.30 ± 1.04	18.02 ± 1.28	p = 0.020*
Corneal Radius	7.68 ± 0.25	7.87 ± 0.22	p = 0.001*
Axial Length/Corneal Radius Ratio	3.19 ± 0.15	3.21 ± 0.15	p = 0.417

Table 3.7 Comparison of right eye ocular biometry parameters (mean ± standard deviation) between females and males. (n = 99) The symbol * indicates significant difference between groups.

3.1.5. Age at Initial Refractive Correction

Amongst the 81 participants who required refractive correction, the reported mean age of initial refractive correction was 10.0 ± 2.9 years, ranging from 5 to 19 years. Correlational analysis revealed that the age at initial refractive correction was moderately correlated to the right spherical equivalent refraction ($r = 0.678$, $r^2 = 0.460$, $p < 0.001$), left spherical equivalent refraction ($r = 0.646$, $r^2 = 0.417$, $p < 0.001$), right axial length ($r = -0.559$, $r^2 = 0.312$, $p < 0.001$), and right vitreous chamber depth ($r = -0.510$, $r^2 = 0.260$, $p < 0.001$) (Figures 3.2 to 3.5). No correlation was found between age of initial correction and corneal thickness ($r = -1.26$, $p = 0.262$), anterior chamber depth ($r = -0.204$, $p = 0.068$), and lens thickness ($r = -0.117$, $p = 0.298$).

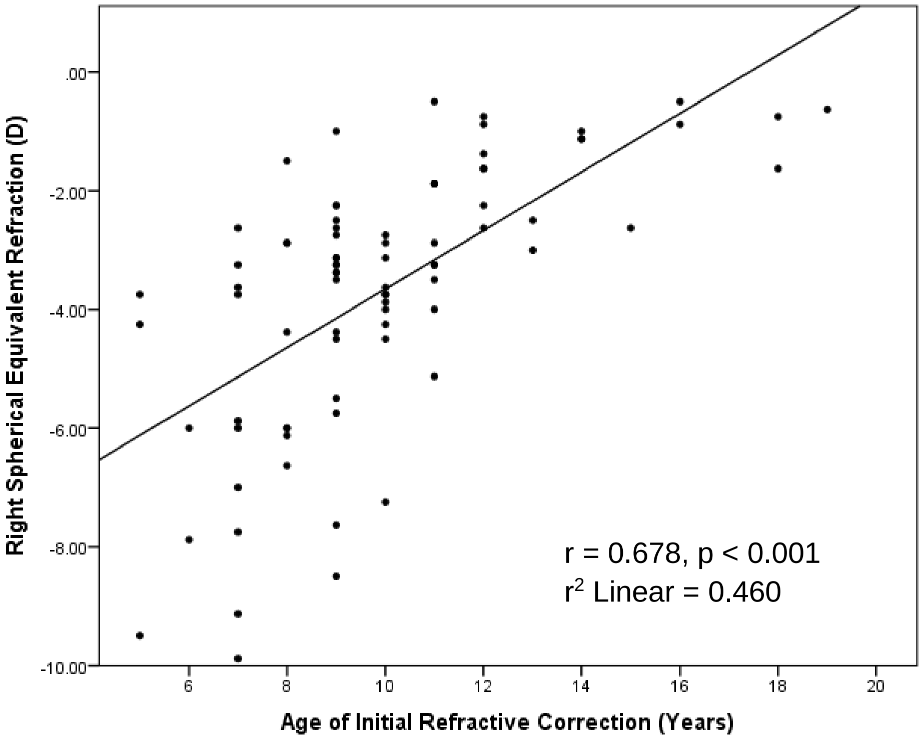

Figure 3.2 Scatterplot of right spherical equivalent refraction and age of initial refractive correction (n = 81).

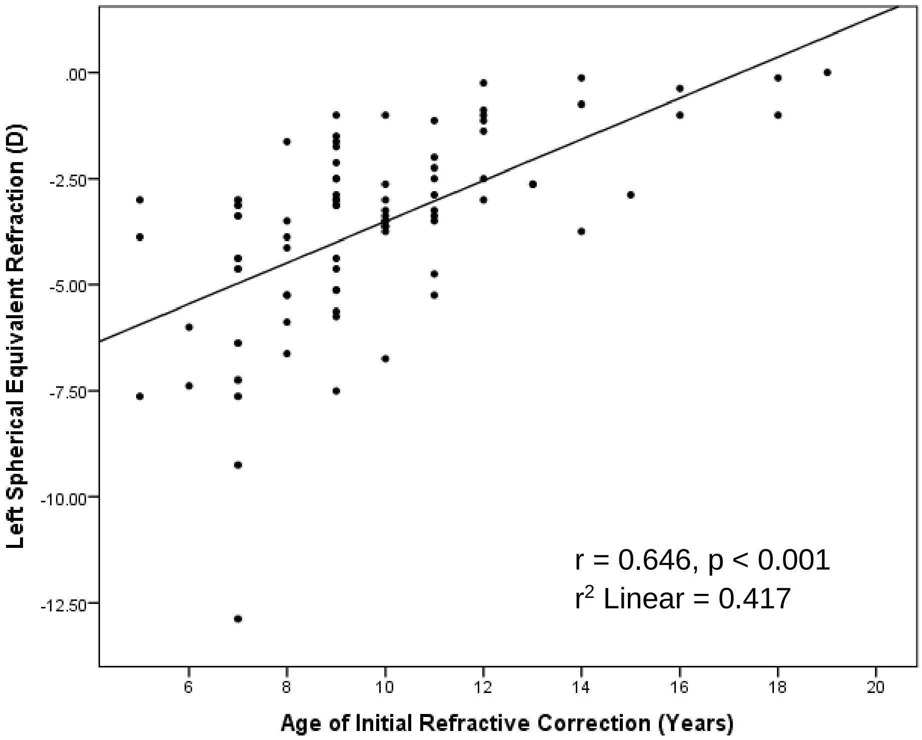

Figure 3.3 Scatterplot of left spherical equivalent refraction and age of initial refraction correction (n = 81).

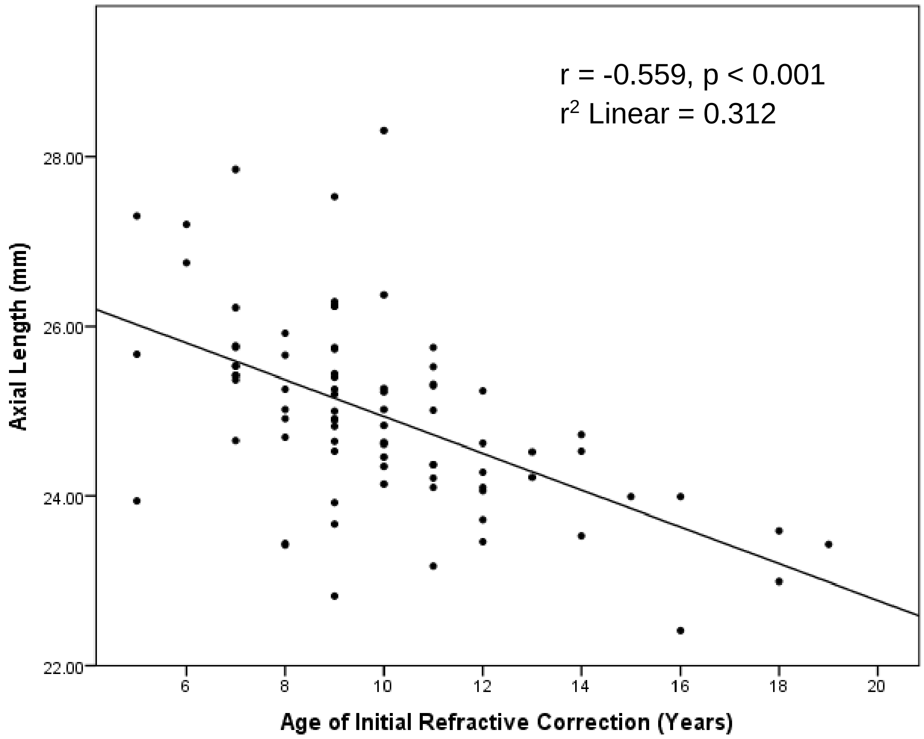

Figure 3.4 Scatterplot of right axial length and age of initial refraction correction (n = 81).

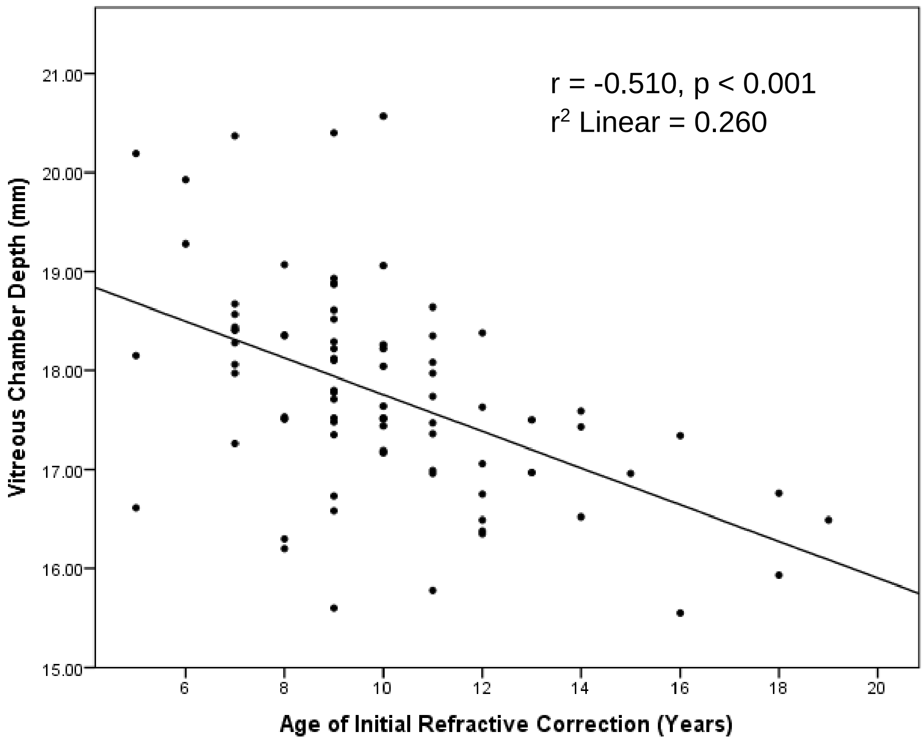

Figure 3.5 Scatterplot of right vitreous chamber depth and age of initial refraction correction (n = 81).

3.1.6. Near Work, Dioptre-Hour, and Outdoor Activities

Across the whole cohort, the mean time spent by participants reading, using the computer, and watching television in a week were 31.4 ± 20.7 hours, 50.5 ± 34.9 hours, and 9.6 ± 8.5 hours, respectively. The calculated Dioptre-Hour was 204.9 ± 104.9, with a range between 47.7 hours and 584.0 hours. Participants also spent 13.5 ± 12.9 hours on outdoor activities, 4.9 ± 5.4 hours on outdoor sports, and a total of 9.0 ± 8.9 hours on indoor and outdoor sports in a week.

When comparing Non-Myopes (n = 18), Low-Myopes (n = 40), and Mod/High-Myopes (n= 41), no significant differences were observed for reading hours per week (p = 0.092), computer hours per week (p = 0.206), TV hours per week (p = 0.672), Dioptre Hours per week (p = 0.236), outdoor hours per week (p = 0.573), outdoor sports per week (p = 0.826), and Indoor/Outdoor sports per week (p = 0.973).

3.1.7. Accommodative Responses

The accommodative error index (AEI) was compared between Non-Myopes, Low-Myopes, and Mod-High-Myopes using the Kruskal Wallis test. There was no significant difference in AEI between the three refractive error groups ($\chi^2(2) = 2.966$, $p = 0.227$) (Table 3.8). The accommodative stimulus response curves (ASRCs) of Non-Myopes (Figure 3.6), Low-Myopes (Figure 3.7) and Mod/High-Myopes (Figure 3.8) show a consistent lag of accommodation for all accommodative stimuli, where all three ASRCs do not differ greatly from one another.

	Non-Myopes (n = 13)	**Low-Myopes** (n = 39)	**Mod/High-Myopes** (n = 47)	**Sig.**
Accommodative Error Index	0.48 ± 0.31	0.61 ± 0.35	0.51 ± 0.30	p = 0.227

Table 3.8 Comparison of accommodative error index (mean ± standard deviation) between Non-Myopes, Low-Myopes, and Mod/High-Myopes.

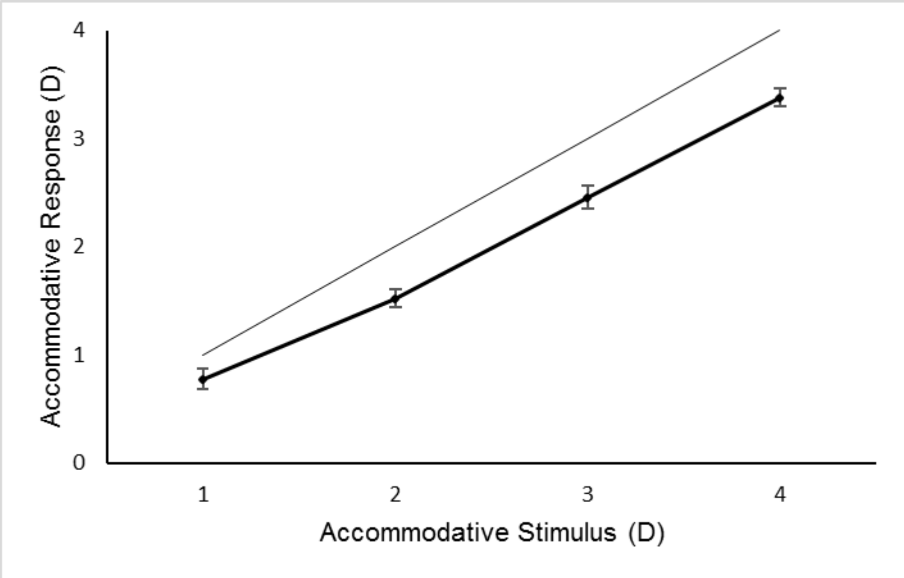

Figure 3.6. Accommodative stimulus response curve of Non-Myopes (n = 13). The darker solid line represents the accommodative stimulus response curve. The error bars represent the standard errors of the mean.

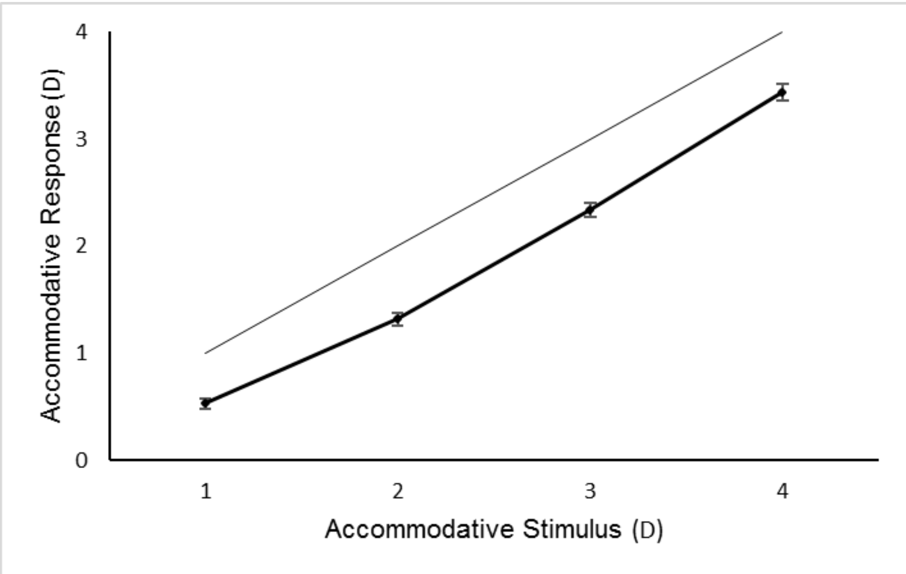

Figure 3.7 Accommodative stimulus response curve of Low-Myopes (n = 39). The darker solid line represents the accommodative stimulus response curve. The error bars represent the standard errors of the mean.

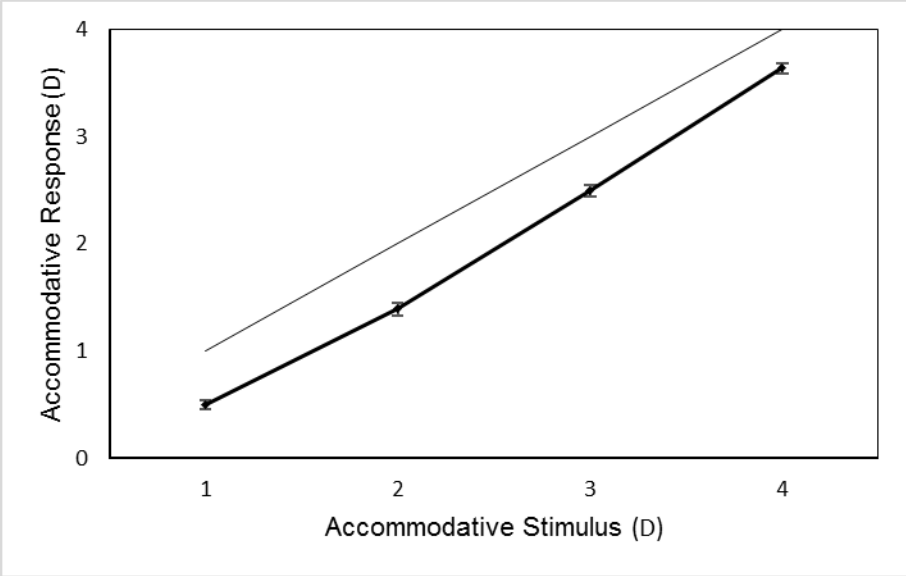

Figure 3.8 Accommodative stimulus response curve of Mod/High-Myopes (n = 47). The darker solid line represents the accommodative stimulus response curve. The error bars represent the standard errors of the mean.

3.1.8. Reported Parental Myopia

When all participants (n= 99) were surveyed on whether their parents had myopia, 55 (55.6 %) participants reported having at least one parent who was myopic, while 35 (35.4 %) participants reported neither of their parents had myopia. Participants who were unsure of the refractive status (n = 9) of at least one parent were excluded from the following analysis, regardless of whether they were sure of the refractive status of the other parent. When comparing participants with no myopic parents and participants with at least one myopic parents, significant differences were found in the right spherical equivalent refraction (Mann Whitney U test, Z = -2.128, p = 0.033) and the right corneal thickness (Mann Whitney U test, Z = -2.152, p = 0.031) (Table 3.9).

	No Myopic Parent (n = 35)	At Least 1 Myopic Parent (n = 55)	Sig.
Right Spherical Equivalent Refraction	-2.33 ± 2.18	-3.41 ± 2.48	p = 0.033*
Right Corneal Thickness	572.26 ± 32.28	557.67 ± 31.32	p = 0.031*
Right Anterior Chamber Depth	3.05 ± 0.26	3.07 ± 0.23	p = 0.766
Right Lens Thickness	3.55 ± 0.18	3.55 ± 0.19	p = 0.817
Right Axial Length	24.38 ± 1.00	24.82 ± 1.28	p = 0.081
Right Vitreous Chamber Depth	17.20 ± 0.99	17.64 ± 1.21	p = 0.076

Table 3.9 Comparisons of refractive and biometric parameters (mean ± standard deviation) between participants with no myopic parents (n = 35) and participants with at least one myopic parent (n = 55).
* indicates significant difference between groups.

3.1.9. Primary School Leaving Examinations

Participants were grouped according to their Primary School Leaving Examinations (PSLE) scores, where 24 (24.2 %) participants scored 199 or lesser, 32 (32.3 %) participants scored between 200 and 219, and 38 (38.4 %) participants scored 220 or better. Between the three independent PSLE score groups, a significant difference in crystalline lens thickness was observed (Kruskal Wallis, $\chi^2(2) = 6.149$, $p = 0.046$). Post-hoc analysis revealed that participants who scored ≥ 220 had significantly thicker crystalline lenses than those who scored ≤ 199 (Mann Whitney U, $Z = -2.437$, $p = 0.015$). No significant differences in age of initial refractive correction, right spherical equivalent refraction, central corneal thickness, anterior chamber depth, axial length, and vitreous chamber depth was detected between the PSLE groups.

	PSLE Score Group			
	≤ 199 (n = 24)	**200 to 219** (n = 32)	**≥ 220** (n = 38)	**Sig.**
Lens thickness (mm)	3.48 ± 0.14	3.53 ± 0.22	3.59 ± 0.18	p = 0.046*

Table 3.10 Lens thickness comparisons (mean ± standard deviation) between different PSLE score groups. Participants who scored ≥ 220 had significantly higher lens thickness than those who scored ≤ 199. The symbol * indicates significant difference between groups.

3.2. Discussion

This section sets out to discuss the baseline findings of this study, as there has been a scarcity of reports on the proportion of refractive error in young adults studying in a post-secondary tertiary institution in Singapore. In addition, no previous study has reported the distribution of ocular biometric components in such a sample of participants. The analysis of the refraction and ocular biometric parameter findings with the age of initial refraction, near work, outdoor activities, accommodative response, parental myopia and academic achievement were compared with previous studies. The invaluable information obtained from this chapter will form a foundation of knowledge on the participants' vision, refractive status and lifestyle, and ocular parameters, and would also aid in the understanding of the longitudinal data in the later chapters.

3.2.1. Demographic Profile

The majority of participants were of Chinese ethnicity, at 89.9 %; this reflects the ethnic distribution of Singapore, which is made up of 74.3 % Chinese, 13.3 % Malay, 9.1 % Indians and 3.2 % other ethnic groups ("Statistics Singapore - Population and Population Structure," 2015). The higher percentage of Chinese in this study is likely a result of the non-probabilistic direct contact sampling method, where the participants whom the author was in contact of, is of a higher Chinese proportion. The age of participants ranged from 16 to 22 at the time of recruitment, where the majority of the participants were in the first and second year of their course of study. Typically, students in the first year of study are 16 to 17 years of age and would graduate the three-year diploma programme at 20 or 21 years of age.

3.2.2. Refractive Error

The proportion of female participants differs significantly from male participants in this study. Females appeared to be more receptive towards participating in this research, according to the author's observation. Despite the gender inequality, there were no significant differences in the sphere, cylinder or spherical equivalent power of each eye, indicating that the refractive status amongst the participants were homogeneous and unaffected by the unequal gender distribution. No significant differences were observed for the sphere, cylinder and spherical equivalent between the right and left eye of all participants. As such, the refraction as well as the ocular biometric parameters of the right eye were used for analysis for each participant. Despite the intention to recruit equal sample sizes for each refractive error group, the sample size for Non-Myopes was lower than that of Low-Myopes and Mod/High-Myopes. A lower sample size can potentially reduce the power of the statistical analysis, with a higher chance of a Type II error, reducing the possibility of finding true significant results. More than the required number of participants were recruited for the Low-Myopes and Mod/High-Myopes groups. Research studies that recruit more than the approved number of participants could put more participants at risk, especially when it is meant to test the effectiveness of interventions that carry risks. In the present study, no additional risk was posed to the additional participants as there was no expected risks other than ocular fatigue and time spent. Recruiting additional participants could also buffer for potential withdrawals, which is not uncommon in longitudinal studies (Moser et al., 2000; Hogan et al., 2004).

Amongst all participants, the proportion of myopia was high at 86.9 % for the right eye and 82.8 % for the left eye. A cohort of younger teenagers from the Singapore Cohort of Study of the Risk Factors for Myopia (SCORM) where children between 11 and 20 of age, with a younger mean age of 13.7 years, were found to have a lower myopic prevalence of 69.5 % (Dirani et al., 2009). Quek et al. (2004) and Saw et al. (2003b) found secondary school students between 15 to 19 years of age to be 73.9 % myopic (≤ -0.50 D). Furthermore, medical students in Singapore who were of a slightly older age group had a myopic prevalence similar to the present study, at 82.0 % (Chow et al., 1990). A more recent study found 89.8 % of medical students to be myopic (≤ -0.50 D) (Woo et al., 2004). In this study, the proportion of hyperopia was the same for both eyes, at 3.0 %. Woo et al. found a slightly lower prevalence of 1.3 % prevalence in medical students (> +0.50 D) in medical students, while Quek et al. found the prevalence of hyperopia to be 1.3 % in secondary school students. The prevalence of hyperopia in the SCORM study (≥ +0.50 D) was higher at 4.5 %.

The prevalence of myopia in this study was not as high as 19-year-old military conscripts in South Korea (Jung et al., 2011), at 96.5 % (< -0.50 D), but similar to military conscripts in Taiwan (mean age 21.58 years) at 86.1 % (≤ 0.50 D) (Lee et al., 2013). Young white adults of 19 to 22 years of age in Western Australia had a much lower myopic prevalence, at 23.7 % (McKnight et al., 2014). The prevalence of myopia was between 48.0 % and 65.0 % in university students in Norway (≤ -0.25 D) (Kinge and Midelfart, 1999; Kinge et al., 2000), 32.9 % in Turkey medical students (≤ -0.75 D) (Onal et al., 2007), between 22.0 % and 27.1 % in Portuguese university students (≤ -0.50 D) (Jorge et al., 2007), and between 92.8 and 95.8 % in Taiwan medical students (≤ -0.25 D) (Lin et al., 1996). The proportion of myopic participants in the present study matches that of Taiwan military conscripts in the study by Lin et al., which is likely due to the same Chinese ethnicity and similar urban living environment.

It is clear that there is a distinct difference in the prevalence of myopia between Eastern and Western regions, where Taiwan (Lin et al., 2004), Hong Kong (Edwards and Lam, 2004), South Korea (Jung et al., 2011), Guang Zhou (He et al., 2009), and Singapore (Koh et al., 2014) exhibit high prevalences compared to major Western cities. However, the prevalence of myopia is increasing around the world. In the United States, the prevalence of myopia increased from 25.0 % to 41.6 % between the early 1970s and the early 2000s (Vitale et al., 2009). A review of literature revealed the prevalence of myopia in Finland had increased over the years in both children and adults (Pärssinen, 2012). In the United Kingdom and Australia, children were increasingly becoming myopic as well (McCullough et al., 2016). In Europe, the prevalence of myopes was found to increase with more recent birth cohorts, where it was suggested that higher levels of education play a contributory role towards this increase (Williams et al., 2015).

It is important to emphasise that differences in the prevalence of myopia exist for distinct living environments in the same geographical region. In Taiwan, myopia is significantly lower in hilly, aboriginal, and rural regions compared to Taipei and Kaohsiung Cities (Lin et al., 2004). Ethnic Chinese children in neighbouring Malaysia had a lower prevalence of myopia compared to Singapore, despite being geographically near and sharing common heritage (Saw et al., 2006). In China, children living in rural areas of Greater Beijing had significantly lesser myopia than those living in urban areas (Guo et al., 2013). The difference in prevalence between different living environments despite being geographically near, highlights the possibility of environmental influences including lesser time spent outdoors, increased reading, and attainment in higher education.

3.2.3. Refractive Correction

Most participants (82.8 %) in this study used either spectacles or contact lenses to correct vision, and only 17.2 % of participants did not use any form of correction at all. However, only 12.1 % used spectacles full-time, which equates to 14.6 % of the 82 participants who required spectacles or contact lenses to correct their vision to see well. As such, 85.4 % of participants who required vision correction did not solely use spectacles as their only form of vision correction, and had the option of contact lens use, or not using any correction at all. Spectacle wear was the main form of refractive correction, with 61.0 % of those who required vision correction using them as their major (≥ 55 %) form of correction. As 28.0 % of those who required refractive correction do not use contact lenses at all, 72.0 % of these participants had been exposed to the use of contact lenses. The percentage of contact lens users among all participants in this study was 59.6 %, of which 94.0% were myopes (≤ -0.50 D).

An earlier study conducted in Singapore on the prevalence of contact lens wear found 21.8 % of myopes used contact lenses (Kelvin et al., 2000). A more recent Hong Kong survey on prescribing trends of contact lenses reported 36.0 % of patients to be contact lens wears, with 96.0 % of these being myopic (Yung et al., 2005). In India, 392 out of 6,850 college students (5.7 %) used contact lenses (Unnikrishnan et al., 2009), while 27.4 % of Brazil university students used contact lenses (Vidotti and Kamegasawa, 2006). The penetration of contact lenses into this cohort of young adults in this study is high, compared to previous studies mentioned. However only 13.4 % of those who require vision correction used contact lenses as a major form (≥ 55 %) of vision correction. The high penetration but low extent of usage is likely due to the majority of the participants being optometry students, as they were introduced to contact lenses during their studies, but did not appear to rely on them for their day-to-day vision needs. It is possible that there will be an increase in the extent of contact lens usage when these students graduate and enter the workforce.

3.2.4. Ocular Biometry

The distribution curves for corneal thickness, corneal radius, lens thickness, axial length and vitreous chamber depth were normal, in agreement with previous studies, with the exception of anterior chamber depth. The distribution curve of anterior chamber depths exhibited leptokurtosis of 2.02, statistical significance in the Shapiro-Wilk test ($p = 0.035$), but with non-significance in the Kolmogorov-Smirnov test ($p = 0.156$), suggesting that the distribution is close to normal.

Female participants were found to exhibit shallower anterior chamber depth, and shorter axial length and vitreous chamber depth compared to males. The CLEERE study reported similar findings where boys exhibited deeper anterior chamber depths and longer axial lengths (Zadnik et al., 2003). Ip et al. (2007) also found 12-year-old Australian boys to have longer axial lengths compared to girls. In a Spanish study of 583 university students, males had significantly longer axial length, flatter corneal radius, and greater lens thickness (Blanco et al., 2008). Osuobeni (1999) investigated ocular components of 152 adult Saudis between 16 to 50 years of age, and reported deeper anterior chamber depths in males, while cornea curves were steeper in females. Mallen et al. (2005) worked with 1,093 Jordanian adults and reported similar findings of steeper corneas in females, and deeper anterior chamber and vitreous chamber depths, and longer axial lengths in males. The findings of Atchison et al. (2008) were similar, where emmetropic males exhibited longer axial length and vitreous chamber depth, and flatter corneas than females, although the authors found no significant difference in anterior chamber depth between genders. The findings of the present study match closely to those from previous studies, where deeper axial lengths and vitreous chamber depths are characteristic of the male gender, while steeper corneal curves are attributed to the female gender.

Importantly, it has been shown that the gender differences in ocular biometric parameters would cease to exist when the height and weight were taken into consideration (Wickremasinghe et al., 2004). As such, ocular biometric data of both genders can be analysed together, with the caveat that there would be a higher variation of eye sizes in the sample. The AL/CR would be an insightful parameter that circumvents the factor of eye size, as the corneal radius and axial length increases with corneal growth. Excessive axial elongation would thus result in a higher AL/CR ratio. Previous studies used contact A-scan sonography to measure ocular biometry, precluding corneal thickness as a variable for analysis. In this study, corneal thickness was not found to be different between male and females, and no relationship existed between refraction and corneal thickness. As such, corneal thicknesses do not appear to play a significant role towards refractive error changes.

3.2.5. Age at Initial Refractive Correction

The moderate and significant correlations between the age of initial refraction and the spherical equivalent power of the right (r = 0.678) and left (r = 0.646) eyes shows that participants who started wearing refractive correction early in life had higher degrees of myopia. As the proportion of myopes is high (81.8 %, including both Low Myopes and Mod/High-Myopes) in this sample, it is likely that almost all participants were myopic when they started their first refractive correction. Hyperopes were less likely to have used refractive correction, as no individual’s hyperopia exceeded +0.75 D spherical equivalent refraction in this study. González et al. (2008) similarly reported significantly higher myopia and longer axial lengths between juvenile onset myopes compared to adult onset myopes, which was in agreement with earlier findings (Grosvenor and Scott, 1993; McBrien and Adams, 1997). Since 73 out of 81 (93.8 %) participants who require refractive correction reported their initial refractive correction to be before 16 years of age, correlational analysis would be a more appropriate analysis technique to investigate the relationships mentioned. Despite having the majority of participants reporting an initial refractive correction younger than 16 years of age, it is still evident from the analysis that early commencement of refractive correction, which is analogous to the onset of myopia in this situation, is related to eventual higher myopia.

3.2.6. Near Work and Outdoor Activities

In the present study, near work does not appear to be related to the current refractive status of participants, as there were no differences in the number of hours spent reading, using the computer, and watching television between Non-Myopes, Low-Myopes and

High-Myopes. The Dioptre-Hour, which takes into account the accommodative effort required for near tasks, was also not associated with the refractive error status of participants. The Orinda Longitudinal Study of Myopia (OLSM) found near work to be a small contributory factor towards myopia (Mutti et al., 2002), where the main risk lies in having parental myopia. Conversely, Saw et al. (2006) reported no association between near work and incident myopia, suggesting that children read more after contracting myopia. Saw also suggested non-verbal intelligent quotient (IQ) to be a more important risk factor than reading (Saw et al., 2004). A more recent study by Jones-Jordan et al. (2011) reported near work activities to be similar between children who went on to become myopic and children who remained emmetropic, and that near work only increased during and after the incidence of myopia.

The amount of near work performed by this sample of participants were not expected to be different between the different refractive error groups as the majority of myopes would have been beyond the stage of myopia incidence, apart from five participants who reported their initial refractive correction of after 16 years of age. In addition, the amount of near work may be more homogeneous amongst young adults as they perform a wide variety of near work tasks (e.g. using smartphones, laptops, and computers), which can be for leisure or academic purposes. The amount of outdoor activities was also not associated with the different refractive error groups, likely due to outdoor activities being protective of myopia incidence but not progression (Guggenheim et al., 2012; Wu et al., 2013). As most participants were already past the stage of myopia incidence, outdoor activities at this stage of life would unlikely be related to the magnitude of myopia, and would be largely dependent on the individual lifestyle of each participant.

3.2.7. Accommodative Responses

The absence of differences in the accommodative error index between the refractive error groups suggests that Non-Myopes, Low-Myopes and Mod/High-Myopes had similar accommodative responses. The similarity in the accommodative stimulus response curves (ASRCs) of the three refractive error groups highlights this finding. Similarly, Abbott et al. (1998) did not find any differences in the ASRCs between emmetropes and myopes, but only in progressing myopes. Nakatsuka et al. (2003) found no differences in the slope of the regression line between myopes and non-myopes, and there were no large lags of accommodation in myopes. Similarly, Harb et al. (2006) reported no differences in accommodative responses between emmetropes and myopes in sustained reading, but greater fluctuations in accommodation in myopes. However, in the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) Study, Mutti et al. (2006) demonstrated that increased accommodative lag was only observed after the onset of myopia, not before. The longitudinal data of the CLEERE study also reported no associations in the lag of accommodation with the progression of myopia (Berntsen et al., 2011). Abbott et al., Harp et al., and Nakatsuka et al. used adult participants which would align better with the present study. As such, the accommodative responses for this sample of young adult participants, agree with previous studies in that there was no difference in static accommodative responses between myopes and non-myopes. It seems likely that accommodative lag increases upon the onset of myopia in children, but is unlikely to be the cause of myopigenesis.

3.2.8. Reported Parental Myopia

The significantly higher spherical equivalent refraction in participants with at least one myopic parent highlights the importance of the latter’s role in the development of myopia. The odds ratio of having myopia was previously presented in the Orinda Longitudinal Study of Myopia as 2.17 and 5.40 for having one and two myopic parents, respectively (Mutti et al., 2002; Jones et al., 2007). Parental myopia can be used to predict the occurrence of future myopia, albeit with low specificity and sensitivity of 81.9 % and 62.5 % respectively, when considering children with hyperopia of MSE +0.75 D or lesser during the first grade of school (Jones-Jordan et al., 2010). Recent findings from the follow-up of the Sydney Myopia Study revealed a similar increase in the odds of myopia, where parental myopia was a significant risk factor for myopia in 6-year-old children, but not 12-year-olds (French et al., 2013b). Studies in Singapore concurred with Western studies and found parental myopia to be an independent risk factor for myopia development (Saw et al., 2002, 2006).

Cohort and longitudinal studies are ideal research designs to investigate the incidence and progression of myopia and its association with parental myopia. The baseline cross-sectional results of the present study are not able to establish a causative relationship of parental myopia towards the progression of myopia. However, the significant difference in refractive error between participants with no parental myopia and those with parental myopia suggests the existence of this relationship. The reporting of parental myopia by participants was subject to recall bias as individuals may not know for certain the refractive status of their parents, which likely explains the slightly weaker statistical significance of $p = 0.03$ compared to previous findings by Saw et al. (2006). It is interesting to note that a significant difference was identified in the corneal thicknesses between participants with no parental myopia and participants with parental myopia. Previous studies discussed either did not analyse parental myopia with ocular biometric parameters, or excluded the analysis of corneal thickness (Saw et al., 2006). More investigation is warranted to explain this difference in corneal thickness between those who had parental myopia those who did not.

3.2.9. Academic Achievement

The Primary School Leaving Examinations (PSLE) score was used to determine the level of academic achievement of the participants at the age of 12 years. The PSLE is a compulsory national examination that determines the academic ability of the child, allowing the allocation of places in secondary schools according to merits. All the participants in this study were polytechnic students, where entry was based on the GCE ‘O’ Levels aggregate score, but not the PSLE. As such, students who did not do well in primary school may perform better in secondary school, gaining entry into the polytechnic. The reverse may happen where students may do well in the PSLE, and subsequently perform poorer in the GCE ‘O’ Levels examination. The PSLE is therefore an appropriate measure to assess the academic performance of the participant at 12 years of age. However, neither refraction or ocular biometric components demonstrated significant differences between the three groups of PSLE scores, with the exception of lens thickness. Participants who did better in their PSLE with a score of at least 220 exhibited thicker crystalline lens compared to participants who performed poorer with a score of 199 or lesser. As the level of statistical significance was not high at $p = 0.046$, and the difference between the means was only 0.11 mm, it is likely that this difference is of little clinical significance.

In the SCORM study, Saw et al. (2007) reported significantly higher rates of myopia in Singapore children with better national examination scores. Mutti et al. (2002) also found higher test scores in myopes, compared with other refractive groups. However, there were no such associations in the present study. Similarly, a study on Hong Kong preschool children did not find any difference in test scores between myopes, emmetropes and hyperopes (Goldschmidt et al., 2001). All primary schools in Singapore use the same curriculum that culminates towards the PSLE. As such, academic pressures in primary school students across the country should not vary widely. Therefore, it is possible that PSLE score is a measurement of the amount of effort put towards preparing for the highstakes examination, but may not represent the continuous and cumulative pressures throughout the duration of primary school studies (Mawhinney et al., 1971). As there were only six participants who scored less than 179, and none scored higher than 260, the sample could suffer from inadequate variance in PSLE scores. Young adults who scored these extreme low or high scores do not typically study in the polytechnic, and may more commonly be studying in other institutions (e.g. Institutes of Technical Education, Junior Colleges). As such, further investigations may also be required to examine the differences in refraction and biometric parameters in participants with a much wider range of PSLE scores.

3.2.10. Summary

The prevalence of myopia in this cohort of young adult tertiary students, at 86.9 %, has not been previously reported, and is higher than that of Singapore secondary school students (73.9 %) (Quek et al., 2004), and similar to that of Singapore medical students (89.8 %) (Woo et al., 2004), both of which were reported more than a decade ago. The majority of participants started using refractive correction prior to the age of 12, and those who started using correction earlier exhibited higher myopia. Spectacle wear was the main form of vision correction, while contact lenses appear to be a less popular mode of correction despite their availability. The reported amount of near work, outdoor activities and the accommodative responses reflect the current lifestyle of the participants and seems unrelated to their refractive status. Parental myopia continues to be a useful indicator that can be clinically used to assess the risk of myopia. However, the use of PSLE score as a measure of academic pressures requires further investigations. The distributions of ocular biometric parameters in this study agrees with previous studies, where it remains to be seen if the longitudinal data would mirror those reported in tertiary students in other countries, which will be described in the next chapter.

Chapter 4: Longitudinal Changes in Ocular Biometry and Refraction in Singapore Young Adults in Tertiary Education

This chapter will examine how refractive error is affected by ocular biometric parameters including corneal thickness, corneal radius, anterior chamber depth, lens thickness, vitreous chamber depth, axial length, and the axial length / corneal radius ratio. Importantly, longitudinal changes, if any, are examined to achieve the main aim of this chapter, as no other study has reported refraction and the ocular biometric findings in young adults who attend pre-university tertiary education in Singapore.

4.1. Results

4.1.1. Participant Completion

The completion rates for this study were high, with 98 out of 99 participants (99.0 %) completing the 12 month visits, and 88 out of 99 participants (88.9 %) completing the 24 month visit. Eleven participants (seven female and four male) did not complete the 24 month study, all of whom failed to reply to text messages that were sent to invite them back for the 12 or 24 month visits.

Visits	Females	Males	Total
Baseline	70 (70.7 %)	29 (29.3 %)	99 (100 %)
12 Month	69 (70.4 %)	29 (29.6 %)	98 (99.0 %)
24 Month	63 (71.6 %)	25 (28.4 %)	88 (88.9 %)

Table 4.1 Completion rates of participants for the baseline, 12 Month, and 24 Month visits.

4.1.2. Ocular Biometry and its Relationship with Refractive Error

A correlation matrix is shown in Table 4.2 for all the ocular biometric components and the spherical equivalent refraction. Spherical equivalent refraction significantly and negatively correlated with axial length ($r = -0.757$, $r^2 = 0.558$, $p < 0.001$) and vitreous chamber depth ($r = -0.748$, $r^2 = 0.560$, $p < 0.001$) with higher correlation strength in Mod/High-Myopes compared to Low-Myopes (Figures 4.1 and 4.2). The relationship between spherical equivalent refraction and AL/CR ratio was the strongest (Figure 4.3), with an r^2 of 0.764. The Mod/High-Myopes group also exhibited strongest correlation between spherical equivalent refraction and AL/CR ratio compared to Low-Myopes. Corneal radius correlated positively with axial length (Figure 4.4) and vitreous chamber depth, which was highest in Non-Myopes, and slightly weaker with Mod/High-Myopes. Mod/High-Myopes exhibited a low correlation of 0.355 between corneal radius and for axial length, compared to a strong correlation of 0.760 in Low-Myopes. The anterior chamber depth appeared to increase with ocular axial growth, as it remained significantly correlated with the axial length and AL/CR ratio for all refractive error groups. The lens thickness negatively correlated to anterior chamber depth in Low-Myopes, which was stronger in Mod/High-Myopes. Lens thickness was strongly correlated with axial length and vitreous chamber depth for Non-Myopes, which became weaker with Low-Myopes and Mod/High-Myopes.

Between Non-Myopes, Low-Myopes, and Mod/High-Myopes, significant differences were observed for AL/CR ratio ($\chi^2(2) = 53.131$, $p < 0.001$), axial length ($\chi^2(2) = 42.502$, $p < 0.001$), and the vitreous chamber depth ($\chi^2(2) = 43.389$ $p < 0.001$) (Table 4.3). Post-hoc analysis using the Mann-Whitney test with manual Bonferroni corrections revealed that Mod/High-Myopes had significantly higher AL/CR ratio at 3.29 ± 0.14, followed by Low-Myopes at 3.13 ± 0.08, where Non-Myopes exhibited the lowest AL/CR ratio at 3.02 ± 0.06. Similarly, Mod/High-Myopes exhibited significantly longer axial length and vitreous chamber depth than Non-Myopes ($p < 0.001$) and Low-Myopes ($p < 0.001$). Low-Myopes also had significantly longer axial length ($p = 0.027$) and vitreous chamber depth ($p = 0.036$) compared to Non-Myopes. There were no differences in corneal radius ($\chi^2(2) = 0.532$, $p = 0.765$), corneal thickness ($\chi^2(2) = 0.092$, $p = 0.955$), anterior chamber depth ($\chi^2(2) = 1.308$, $p = 0.520$), and lens thickness ($\chi^2(2) = 1.680$, $p = 0.432$) between Non-Myopes, Low-Myopes, and Mod/High-Myopes.

A multiple regression analysis was performed to determine the most significant ocular biometric parameters that contribute towards refractive error (Table 4.4). Corneal radius, corneal thickness, anterior chamber depth, lens thickness, axial length, vitreous chamber depth and AL/CR ratio were used as the independent predictors. The AL/CR ratio was found to be the most significant factor that influenced refractive error, followed by anterior chamber depth, corneal radius, and lens thickness ($F = 227.028$, $p < 0.001$). Corneal thickness, axial length and vitreous chamber depth were excluded from the analysis that used the step-wise method. The equation for the regression model was: RX = 66.125 + (AL/CR x -17.827) + (ACD x 2.035) + (CR x -1.602) + (LT x -1.724), with an r^2 value of 0.952 and an adjusted r^2 value of 0.902. The regression model explained 90.2 % of the variances of refractive error.

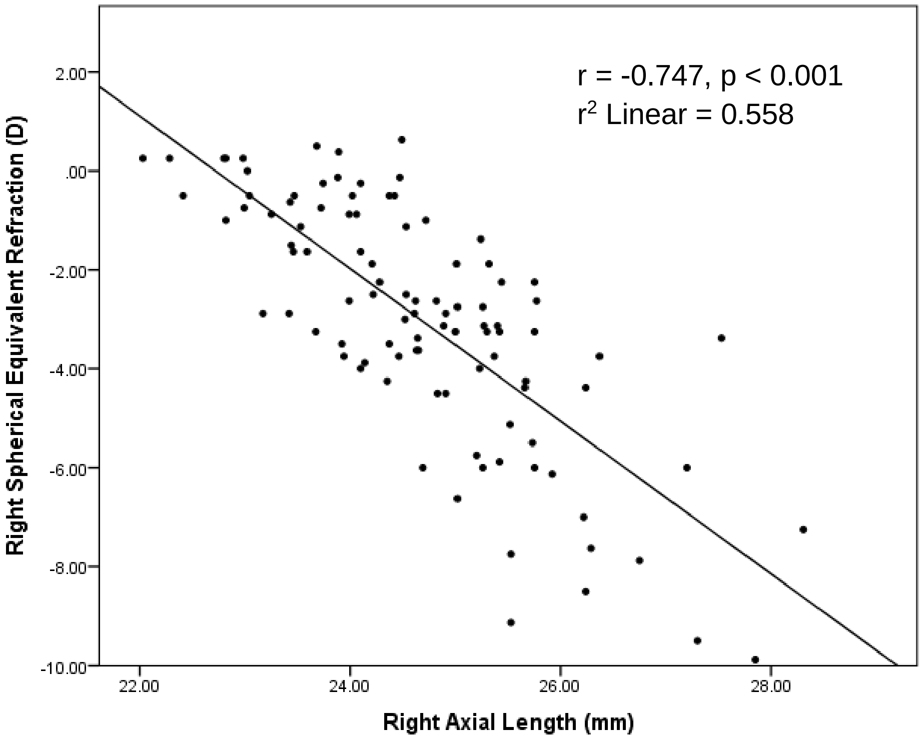

Figure 4.1 Scatterplot of right spherical equivalent refraction and right axial length. (n = 99).

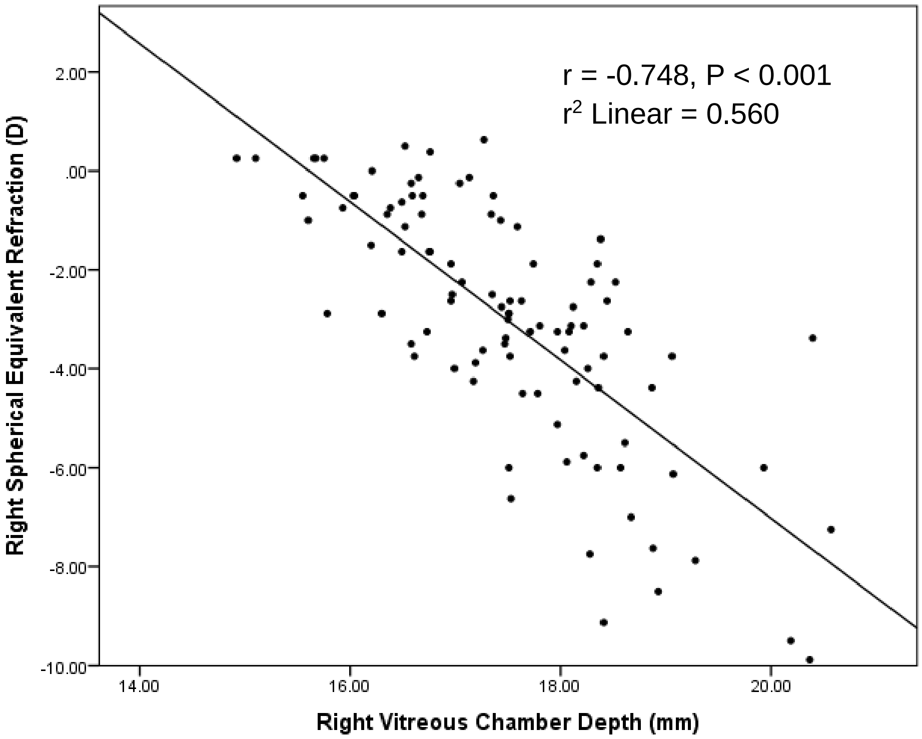

Figure 4.2 Scatterplot of right spherical equivalent refraction and right vitreous chamber depth (n = 99).

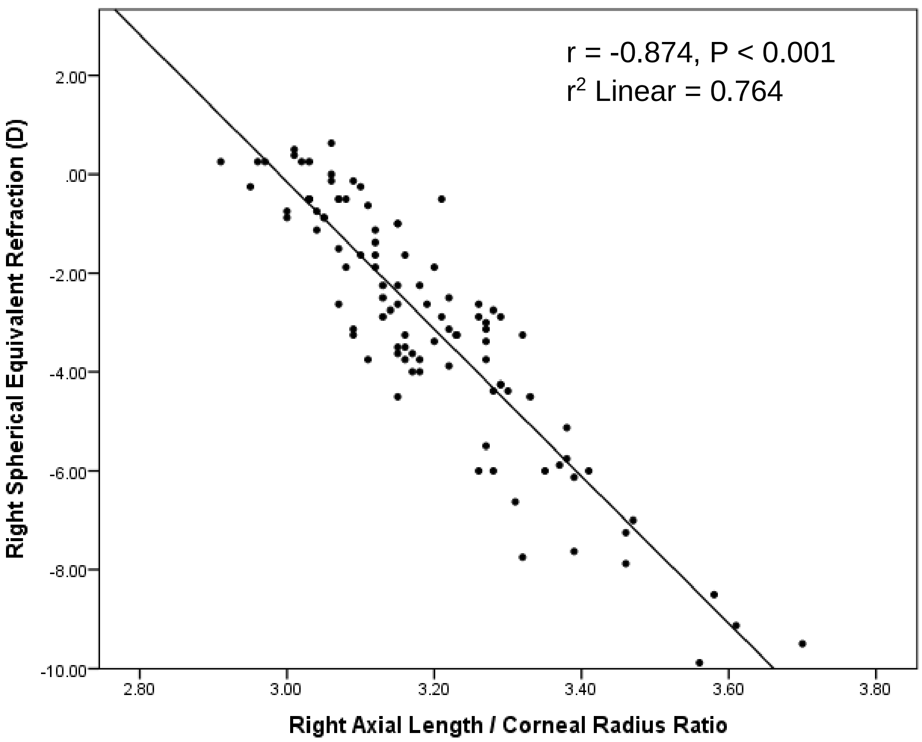

Figure 4.3 Scatterplot of right spherical equivalent refraction and right AL/CR ratio (n = 99).

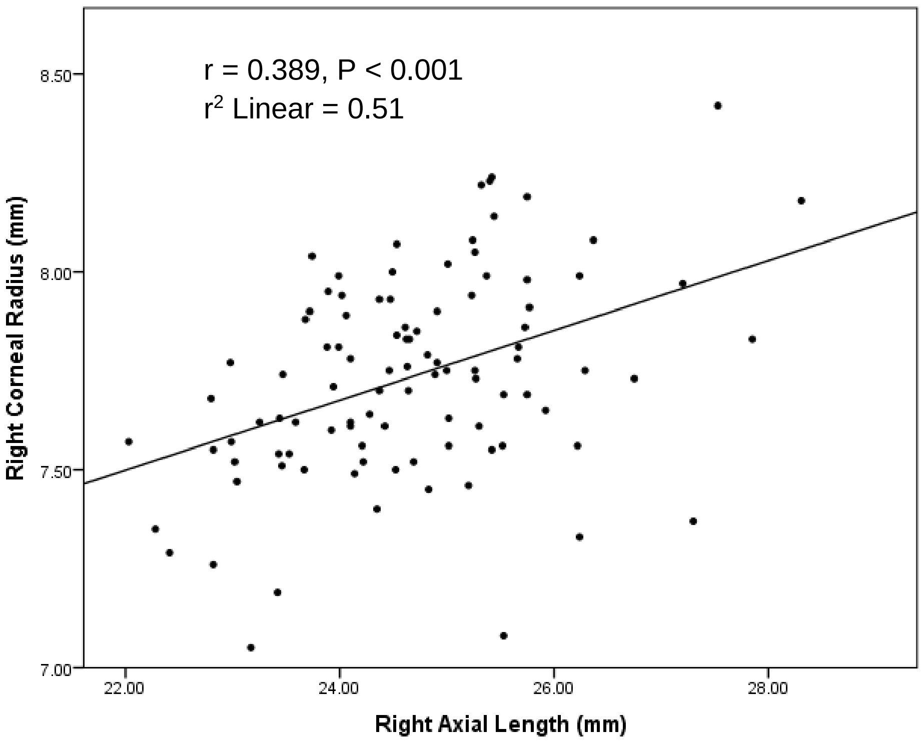

Figure 4.4 Scatterplot of right corneal radius and right axial length (n = 99).

Variables		CT	CR	ACD	LT	AL	VCD	AL/CR
SE	NM	-0.180	0.017	-0.037	0.203	-0.125	-0.125	-0.268
	LM	-0.417$^{\#}$	-0.071	-0.243	0.101	-0.464$^{\#}$	-0.473$^{\#}$	-0.680§
	MHM	0.234	0.276	-0.304*	0.207	-0.534§	-0.521§	-0.767§
		0.016	0.112	-0.190	0.003	-0.747§	-0.748§	-0.874§
CT	NM		0.495	-0.184	-0.634*	0.292	0.451	-0.169
	LM		0.000	-0.002	-0.131	0.137	0.160	0.221
	MHM		0.228	-0.117	0.093	-0.002	-0.031	-0.109
			0.143	-0.055	-0.066	0.041	0.044	0.001
CR	NM			0.335	-0.523	0.769$^{\#}$	0.863§	
	LM			0.052	-0.134	0.760§	0.774§	
	MHM			-0.021	0.157	0.355*	0.359*	
				0.048	-0.026	0.389§	0.400§	
ACD	NM				-0.294	0.786$^{\#}$	0.577*	0.866§
	LM				-0.328*	0.349*	0.129	0.540§
	MHM				-0.531§	0.602§	0.461$^{\#}$	0.622§
					-0.428§	0.428§	0.294$^{\#}$	0.454§
LT	NM					-0.641*	-0.768$^{\#}$	-0.360
	LM					-0.212	-0.303	-0.214
	MHM					-0.227	-0.307*	-0.360*
						-0.183	-0.251*	-0.197
AL	NM						0.929§	
	LM						0.942§	
	MHM						0.959§	
							0.974§	

*P < 0.05, $^{\#}$P < 0.01, §P < 0.001

Table 4.2 Correlation matrix of spherical equivalent refraction and corneal thickness (CT), corneal radius (CR), anterior chamber depth (ACD), lens thickness (LT), vitreous chamber depth (VCD), axial length (AL), and axial length / corneal radius ratio (AL/CR) according to Non-Myopes (NM), Low-Myopes (LM), and Mod/High-Myopes (MHM) (n = 99).

	Non-Myopes^{A} (n = 13)	**Low-Myopes^{B}** (n = 39)	**Mod/High-Myopes^{C}** (n = 47)	**Sig.**	**Pairwise Comparisons**
Corneal Radius (mm)	7.76 ± 0.21	7.74 ± 0.28	7.73 ± 0.26	p = 0.765	
Axial Length / Corneal Radius Ratio	3.02 ± 0.06	3.13 ± 0.08	3.29 ± 0.14	p < 0.001§	A<B§, A<C§, B<C§
Corneal Thickness (μm)	562.54 ± 20.8	562.38 ± 34.25	564.43 ± 34.77	p = 0.955	
Anterior Chamber Depth (mm)	2.98 ± 0.3	3.09 ± 0.27	3.09 ± 0.24	p = 0.520	
Lens Thickness (mm)	3.6 ± 0.23	3.51 ± 0.17	3.55 ± 0.18	p = 0.432	
Axial Length (mm)	23.4 ± 0.8	24.18 ± 0.84	25.45 ± 1.04	p < 0.001§	A<B*, A<C§, B<C§
Vitreous Chamber Depth (mm)	16.25 ± 0.77	17.02 ± 0.82	18.24 ± 0.96	p < 0.001§	A<B*, A<C§, B<C§

*P < 0.05, $^{\#}$P < 0.01, §P < 0.001

Table 4.3 Ocular biometric parameters (mean ± standard deviation*)* between different refractive error groups (n = 99).

Variables	β	Sig.
AL/CR Ratio	-17.827	$p < 0.001^{§}$
Anterior Chamber Depth (mm)	2.035	$p < 0.001^{§}$
Corneal Radius (mm)	-1.602	$p < 0.001^{§}$
Lens Thickness (mm)	-1.724	$p < 0.001^{§}$
Corneal Thickness (μm)	0.019	$p = 0.553$
Axial Length (mm)	0.263	$p = 0.729$
Vitreous Chamber Depth (mm)	-0.097	$p = 0.878$

*P < 0.05, $^{\#}$P < 0.01, §P < 0.001

Table 4.4 Beta coefficients and significance of variables used in the multiple regression analysis for refractive error.

4.1.3. Longitudinal Changes in Refractive Error

Out of the 99 participants who attended the baseline visit, 88 participants completed the 24 month visit. The 11 participants who did not respond to reminders to attend the follow-up visits were excluded from the longitudinal analysis. The longitudinal analysis examined data from the baseline, 12 month, and 24 month visits, where the change in refractive error was compared between the 24 month visit and the baseline. The range of differences in spherical equivalent powers between the baseline and the 24 month visits of the right eye was from SE -0.88 D to +1.25 D (Figure 4.5). Comparing the changes in spherical equivalent power over the 24 month period, 68 (77.3 %) participants did not experience a significant change in refraction of at least SE ± 0.50 D. Five (5.7 %) participants experienced increase in myopia of the right eye by at least SE -0.50 D, while 15 (17.0 %) participants had a hyperopic shift of at least SE +0.50 D of the right eye (Table 4.5). Eight out of 88 (9.1 %) participants experienced a myopic shift of SE -0.37 D or worse, compared to 22 (25.0 %) participants with a hyperopic shift of SE +0.37 D or more over the course of two years. The percentage of myopes, hyperopes and emmetropes at the 24 month visit was 84.1 %, 4.5 %, and 11.4 %, compared to 86.9 %, 2.0 %, and 11.1 % at the baseline visit (Table 4.6).

Analyses were performed to examine the changes in refractive error over the course of 24 months. Across the whole cohort, significant differences were found between the baseline, 12 month visits, and 24 month visits for the right spherical power (Friedman Test, $\chi^2(2) = 15.752$, $p < 0.001$) and right spherical equivalent power (Friedman Test, $\chi^2(2) = 12.749$, $p = 0.002$) (Table 4.7). Manual post-hoc analysis using the Wilcoxon Signed Rank Test with manual Bonferroni corrections revealed significantly more negative refractions during the baseline visit compared to the 12 month and 24 month visits for the right spherical and spherical equivalent powers ($p < 0.01$). When the mean change between the 24 month visit and the baseline was compared between Non-Myopes, Low-Myopes and Mod/High-Myopes, no significant differences were found for the spherical power (Kruskal Wallis Test, $\chi^2(2)$ =

0.390, p = 0.823), cylindrical power (Kruskal Wallis Test, $\chi^2(2) = 1.197$, p = 0.550), and the spherical equivalent power (Kruskal Wallis Test, $\chi^2(2) = 1.006$, p = 0.605) (Table 4.8).

	≥ +0.37 D	**≥ +0.50 D**	**≤ -0.37 D**	**≤ -0.50 D**
Non-Myopes (n = 13)	3 (23.1 %)	1 (7.7 %)	2 (15.4 %)	2 (15.4 %)
Low-Myopes (n = 34)	6 (17.6 %)	5 (14.7 %)	2 (5.9 %)	1 (2.9 %)
Mod/High-Myopes (n = 43)	13 (30.2 %)	9 (20.9 %)	4 (9.30 %)	2 (4.7 %)
Total	22 (25.0 %)	15 (17.0 %)	8 (9.1 %)	5 (5.7 %)

Table 4.5 Number of participants with significant change in refractive error, according to their refractive error group at baseline (n = 88).

	Right Eye	
	Baseline	24 month
Myopic	86.9 %	84.1%
Hyperopic	2.0 %	4.5%
Emmetropic	11.1 %	11.4%

Table 4.6 Comparison of the proportion of myopic, hyperopic and emmetropic eyes between the baseline and the 24 month visit (n = 88).

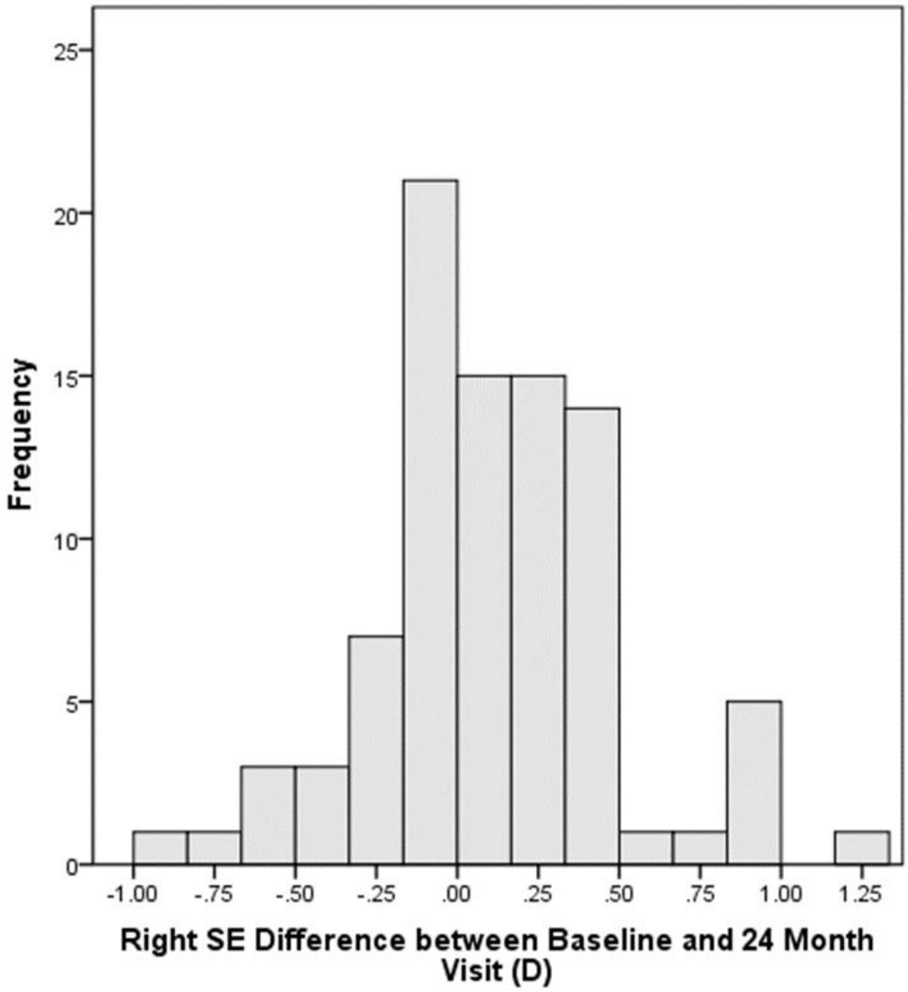

Figure 4.5 Frequency histogram of the spherical equivalent difference between the baseline and the 24 month visit for all right eyes (n = 88). Negative values indicate myopic shifts; positive value indicate hyperopic shifts.

n = 88	Baseline c	12 Month (B)	24 Month (C)	Sig.	Pairwise Comparisons
Sphere	-2.70 ± 2.23 D	-2.56 ± 2.26 D	-2.56 ± 2.27 D	$p < 0.001^{\S}$	A > $B^{\S}$, A > $C^{\#}$
Cyl	-0.69 ± 0.65 D	-0.68 ± 0.67 D	-0.70 ± 0.67 D	p = 0.491	
Spherical Equivalent	-3.05 ± 2.39 D	-2.90 ± 2.41 D	-2.91 ± 2.40 D	p = 0.002	A > $B^{\S}$. A > $C^{\#}$

$^{\#}P < 0.01$, $^{\S}P < 0.001$

Table 4.7 Comparison of refractive error (mean ± standard deviation) between the baseline, 12 month visit, and 24 month visit (n = 88).

n = 88	**Non-Myopes (A)** (n = 13)	**Low-Myopes (B)** (n = 34)	**Mod/High-Myopes (C)** (n = 43)	Sig.
Sphere	0.11 ± 0.52	0.11 ± 0.37	0.17 ± 0.4	p = 0.823
Cyl	-0.07 ± 0.32	-0.02 ± 0.27	0.01 ± 0.28	p = 0.550
Spherical Equivalent	0.08 ± 0.52	0.10 ± 0.33	0.18 ± 0.39	p = 0.605

Table 4.8 Comparison of the mean changes in refractive error (mean change ± standard deviation) between the baseline and the 24 month visit for each refractive error group (n =88).

4.1.4. Longitudinal Changes in Ocular Biometry

Changes in ocular biometric parameters were compared between the baseline, 12 month and 24 month visits with ANOVA repeated measures (Table 4.9). There were no significant differences between the three visits for corneal radius ($F(2,174) = 1.672$, $p = 0.191$), or for the AL/CR ratio ($F(1.749,152.122) = 1.429$, $p = 0.243$). Mean corneal thickness was 563.0 ± 32.2 µm at baseline, 562.86 ± 32.8 µm at the 12 month visit, and 561.67 ± 32.1 µm at the 24 month visit. Borderline statistically significant differences between the three visits ($F(2,174) = 3.358$, $p = 0.037$) were observed. However, there was no significant differences in post-hoc Bonferroni pairwise comparisons between the baseline and 12 month visit ($p = 1.000$), baseline and 24 month visit ($p = 0.077$), and the 12 month and 24 month visit ($p = 0.089$).

No change in the anterior chamber depths was detected between the three visits, ($F(1.483,129.005) = 1.692$, $p = 0.195$). However, significant differences were present for the lens thickness with means of 3.55 ± 0.19 mm, 3.58 ± 0.19mm, and 3.59 ± 0.19 mm for the baseline, 12 month visit, and 24 month visit, respectively ($F(1.552,135.007) = 23.98$, $p < 0.001$), showing increasing lens thickness over time. Post-hoc tests with Bonferroni adjustments revealed the baseline lens thickness to be significantly thinner than the 12 month ($p < 0.001$) and the 24 month visit ($p < 0.001$). Significant differences in axial length were observed, where the axial length at the 24 month visit was significantly longer by only 0.02 mm compared to the 12 month visit ($p = 0.006$) with Bonferroni post-hoc analysis. There was no significant difference in vitreous chamber depth between the three visits ($F(2,174) = 1.721$, $p = 0.182$).

n = 88	Baseline (A)	12 Month (B)	24 Month (C)	Sig.	Pairwise Comparisons
Corneal Radius (mm)	7.73 ± 0.25	7.72 ± 0.25	7.73 ± 0.25	p = 0.191	
AL/CR Ratio	3.19 ± 0.14	3.19 ± 0.14	3.19 ± 0.15	p = 0.243	
Corneal Thickness (µm)	563.01 ± 32.15	562.86 ± 32.77	561.69 ± 32.10	p = 0.037	NS
Anterior Chamber Depth (mm)	3.06 ± 0.25	3.05 ± 0.26	3.05 ± 0.26	p = 0.195	
Lens Thickness (mm)	3.55 ± 0.19	3.58 ± 0.19	3.59 ± 0.19	P < 0.001	A < B§, A < C§
Axial Length (mm)	24.64 ± 1.14	24.64 ± 1.15	24.66 ± 1.16	P = 0.027	B < C$^{\#}$
Vitreous Chamber Depth (mm)	17.47 ± 1.10	17.45 ± 1.10	17.46 ± 1.11	P = 0.182	

$^{\#}$P < 0.01, §P < 0.001, NS = No Significance

Table 4.9 Ocular biometric parameters (mean ± standard deviation) between the baseline, 12 month visit, and the 24 month visit (n = 88).

4.1.5. Ocular Biometry Changes Between Refractive Groups

Differences in ocular biometric parameters between the baseline and the 24 month visit were calculated and compared between Non-Myopes, Low-Myopes and Mod/High-Myopes (Table 4.10). There were no significant differences in the mean change values for corneal radius ($\chi^2(2) = 0.100$, $p = 0.951$), AL/CR ratio ($\chi^2(2) = 0.547$, $p = 0.761$), corneal thickness ($\chi^2(2) = 1.580$, $p = 0.454$), lens thickness ($\chi^2(2) = 1.032$, $p = 0.597$), axial length ($\chi^2(2) = 0.393$, $p = 0.822$), or vitreous chamber depth ($\chi^2(2) = 0.476$, $p = 0.788$) when analysed with the Kruskal Wallis Test. There were significant differences in the change in anterior chamber depth between the three refractive groups ($\chi^2(2) = 7.211$, $p = 0.027$). Post-hoc analysis using the Wilcoxon Signed Rank Test with manual Bonferroni corrections was performed where statistical significance requires $p < 0.017$. Non-Myopes were found to exhibit lesser change in anterior chamber depths compared to Mod/High-Myopes ($p = 0.010$). There was however no significant difference in the mean change of anterior chamber depth between Non-Myopes and Low Myopes ($p = 0.045$), and between Low-Myopes and Mod/High-Myopes ($p = 0.280$).

4.1.6. Relationship Between Ocular Biometric and Refractive Error Changes

To investigate into the factors that were associated with the change in lens thickness described in Section 4.1.3, step-wise multiple regression analysis was performed (Table 4.11). The changes in anterior chamber depth, corneal thickness and spherical equivalent over the 24 month period were found to significantly affect the variance of the change in lens thickness ($r^2 = 0.684$, adjusted $r^2 = 0.673$, $F = 60.745$, $p < 0.001$). The changes in corneal radius, AL/CR ratio, axial length, and vitreous chamber depth were excluded during the analysis. The model explained 67.3 % of the variance of the change in lens thickness over the 24 month period, with the following equation: LT Change = 0.032 + (ACD Change x -0.596) + (CCT Change x -0.001) + (SE Change x -0.016).

A second multiple regression analysis was performed to determine the ocular biometric parameters that influenced the change in spherical equivalent power over the course of 24 months (Table 4.12). The change in lens thickness and axial length was found to account for 18.9% of the variance of the change in spherical equivalent power ($r^2 = 0.207$, adjusted $r^2 = 0.189$, $F = 11.126$, $p < 0.001$). The increase in lens thickness as well as the axial length were found to be associated with more negative refractive errors. The equation for the model was as follows: SE Change = 0.299 + (LT Change x -3.456) + (AL Change x -1.294).

	Non-Myopes (A) (n = 11)	**Low-Myopes (B)** (n = 34)	**Mod/High-Myopes (C)** (n = 43)	**Sig.**	**Pairwise Comparisons**
Corneal Radius (mm)	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.03	p = 0.951	
AL/CR Ratio	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.02	p = 0.761	
Corneal Thickness (µm)	-1.09 ± 5.77	-1.97 ± 5.42	-0.86 ± 5.48	p = 0.454	
Anterior Chamber Depth (mm)	-0.05 ± 0.04	-0.01 ± 0.05	0.00 ± 0.05	p = 0.027	A < C*
Lens Thickness (mm)	0.05 ± 0.05	0.04 ± 0.04	0.04 ± 0.04	p = 0.597	
Axial Length (mm)	0.01 ± 0.05	0.01 ± 0.08	0.03 ± 0.12	p = 0.822	
Vitreous Chamber Depth (mm)	0.00 ± 0.05	-0.01 ± 0.07	0.00 ± 0.12	p = 0.788	

*P < 0.05

Table 4.10 The change in ocular biometric parameters (mean change ± standard deviation) between the baseline and the 24 month visit for Non Myopes (A), Low-Myopes (B), and Mod/High-Myopes (C) (n = 88).

Variables	β	Sig.
ACD Change	-0.596	$p < 0.001$
CCT Change	-0.001	$p = 0.002$
SE Change	-0.016	$p = 0.013$
CR Change	0.032	$p = 0.930$
AL/CR Ratio Change	-0.010	$p = 0.818$
AL Change	0.029	$p = 0.825$
VCD Change	-0.114	$p = 0.915$

Table 4.11 Beta coefficients and significance of variables used in the multiple regression analysis for the change in lens thickness over 24 months.

Variables	β	Sig.
LT Change	-3.456	$p < 0.001$
AL Change	-1.294	$p = 0.001$
CR Change	0.103	$p = 0.999$
AL/CR Ratio Change	-0.124	$p = 0.456$
CCT Change	0.030	$p = 0.937$
VCD Change	0.070	$p = 0.091$
ACD Change	-0.049	$p = 0.358$

Table 4.12 Beta coefficients and significance of variables used in the multiple regression analysis for the change in right spherical equivalent over 24 months.

4.2. Discussion

This section will discuss the correlation findings between spherical equivalent refractive error, corneal thickness, corneal radius, anterior chamber depth, lens thickness, vitreous chamber depth, axial length, and the axial length / corneal radius ratio. As this was the first study that examined these ocular biometric parameters in addition to refractive error in young adults studying in a tertiary institution in Singapore, the findings will be contrasted with the previous studies conducted on participants of similar age groups. Of importance are the two-year longitudinal changes in refractive error and ocular biometric parameters in this sample of Singapore young adults, which has yet to be described in literature. As such, the results of the current study will be compared with the findings of previous studies that reported progression in myopia and axial elongation in university students (Lin et al., 1996; Kinge et al., 1999; Kinge and Midelfart, 1999; Jorge et al., 2007; Jacobsen et al., 2008).

4.2.1. The Relationships between Ocular Biometry and Refractive Error

4.2.1.1. Corneal Thickness

The stretching of the sclera during excessive elongation of the eye in myopia presumably would cause changes to the cornea (Von Bahr, 1956; Chang et al., 2001). However, corneal thickness was found to be similar between Non-Myopes, Low-Myopes, and Mod/High-Myopes, where correlations with axial length, vitreous chamber depth and AL/CR ratio were not statistically significant; this was in concurrence with the findings of Shimmyo and Orloff (2005) and Oliveira et al. (2006). A cross-sectional study on 716 Singapore Chinese participants did not find any correlation between corneal thickness and axial length (Fam et al., 2006). In spite of this, the Singapore Malay Eye Study reported significantly different corneal thickness between different bands of axial length, where every 1 mm increase in axial length was associated with a 1.9 µm increase in corneal thickness (Su et al., 2009). Chen et al. (2009) examined 400 Taiwanese Chinese adults between the age of 40 and 80 years, and reported that there were no significant correlations between corneal thickness and axial length or refractive error.

The present study was the first to investigate the correlations between corneal thickness and other ocular biometric parameters in young adults of a specific age range. Corneal thickness appears to be unrelated to axial length, vitreous chamber depth, AL/CR ratio, anterior chamber depth, or corneal radius. Of interest was the significant correlation between corneal thickness and spherical equivalent refraction only in Low-Myopes. As there was no obvious trend in the correlation coefficients for the three refractive error groups, this finding is unlikely to be of clinical significance unless further investigations with larger sample size could be conducted. In addition, the high correlation between corneal thickness and lens thickness only in Non-Myopes also requires further examination with a larger sample.

4.2.1.2. Corneal Radius

The positive correlation of axial length and vitreous chamber depth with corneal radius, demonstrated that the cornea flattens with axial elongation. Non-Myopes exhibited the strongest association between corneal radius and axial length as well as vitreous chamber depth, which was in agreement with the early findings of Sorsby (1956), who also found the correlation between corneal radius and axial length to be much higher in emmetropes than myopes. When not classified according to refractive error, a weaker correlation between corneal radius and axial length as well as with refractive error could be expected (Grosvenor and Scott, 1991; Goss et al., 1997; Osuobeni, 1999; Chang et al., 2001; Olsen et al., 2007).

Despite the established relationship between axial length and corneal radius, there was no significant difference in corneal radius between Non-Myopes, Low-Myopes and

Mod/High-Myopes in the present study. This is contrary to the findings of Grosvenor and Scott (1991), where myopes were reported to exhibit stronger corneal power. Goss et al. (1997) reported steeper cornea curves in myopes compared to emmetropes, while Blanco et al. (2008) found moderate myopes to exhibit steeper corneas than low myopes, emmetropes and hyperopes. On the contrary, McBrien and Adams (1997) did not find any difference in corneal radius between myopes, hyperopes and emmetropes.

The weaker correlations between corneal radius and axial length or vitreous chamber depth in myopes may be attributed the breakdown of emmetropisation. During ocular growth, the cornea flattens to reduce its refracting power, in order to ensure light focuses on the retina (Zadnik et al., 2004). However, when the eye elongates excessively, the cornea is not able to continue to flatten (Scott and Grosvenor, 1993). Continual axial elongation without the compensatory effects of the cornea brings about myopia, where the excessive stretching of the eye causes corneal steepening (van Alphen, 1961; Sorsby and Leary, 1968). The axial elongation and corneal steepening during myopia progression effectively breaks down the relationship between axial length and corneal radius. In the present study, a weaker relationship is observed between corneal radius and greater axial lengths. Increased corneal curvature is likely to be observed in higher myopes where excessive stretching of the eyeball causes corneal steepening. Since moderate and high myopes were grouped together in this study due to the smaller numbers of higher myopes, the resultant effect of increased corneal curves is thus not pronounced.

4.2.1.3. Anterior Chamber Depth

The significant positive relationship between anterior chamber depth and axial length infers that anterior chamber depth increases in tandem with axial elongation. This relationship is also present with the AL/CR ratio, but lesser with vitreous chamber depth. One reason why vitreous chamber depth is less associated with the anterior chamber depth is that it is less representative of the size of the entire globe. Mallen et al. (2005) reported a similar negative correlation between refractive error and anterior chamber depth in Jordanian adults. Yekta et al. (2010) also found significant increase in anterior chamber depth with axial length in Iranian carpet weavers, where significantly different findings were observed between refractive error types. The relationship between the decrease in refraction (i.e. increase in myopia) and increase in anterior chamber depth was more significant in higher myopia, which can be explained by axial elongation. It is apparent from the poorer correlation between anterior chamber depth and refractive error in Non-Myopes that refraction in this group could exist with varying axial lengths, depending on the size and stature of the each individual (Eysteinsson et al., 2005).

Earlier findings by Grosvenor and Scott (1991) revealed youth-onset myopes to have deeper anterior chambers than emmetropes, but not adult-onset myopes. Similarly, McBrien and Adams (1997) reported myopes exhibited deeper anterior chambers than emmetropes in adult microscopists. Osuobeni (1999) found significant differences in anterior chamber depth between Saudi Arabian myopes, emmetropes and hyperopes, but not with the magnitude of refractive error. Conversely, Goss et al. (1997) did not find any difference in anterior chamber depth between myopic and emmetropic optometry students. Blanco et al. (2008) also reported similar anterior chamber depth readings when comparing hyperopic, emmetropic, low myopic, and moderate myopic university students. The present study corresponds to the findings of Blanco et al. (2008) and Goss et al. (1997) where the lack of difference in anterior chamber depth between Non-Myopes, Low-Myopes and Mod/High-Myopes simply implied that the variation in eye sizes for the given refractive error resulted in a homogenous distribution within each group.

4.2.1.4. Crystalline Lens Thickness

Lens thickness was negatively correlated with axial length and vitreous chamber depth in Non-Myopes, a relationship which became weaker with increasing axial elongation. Lens thickness was also significantly correlated with AL/CR for Mod/High-Myopes, suggesting that lens thickness decreases with increasing myopia. Crystalline lens thickness was similar between Non-Myopes, Low-Myopes and Mod/High-Myopes, in agreement with the findings by Grosvenor and Scott (1991), who reported no differences in lens thickness, or lens power between emmetropes, early-onset myopes, and adult-onset myopes. Similarly, Blanco et al. (2008) found no significant difference in lens thickness between hyperopes, emmetropes, low myopes and moderate myopes. Mallen et al. (2005) and Osuobeni (1999), however, reported that the crystalline lens was thinner in myopic eyes. Although McBrien and Adams (1997) could not find any significant differences in lens thickness between various refractive error groups, a reduction in lens thickness was associated with adult-onset myopes after one year.

In the Reykjavik Eye Study, lens power was noted to be negatively correlated with refraction, with a stronger negative correlation to axial length (Olsen et al., 2007). Likewise, Yekta et al. (2010) described a significant relationship between spherical equivalent refraction and lens thickness, with myopes exhibiting non-significantly thinner lenses than non-myopes. Conversely, Goss et al. (1997) found no significant correlations between lens thickness and refraction, and between lens power and refraction in university students. There was also no significant difference in lens thickness or lens power between myopes and hyperopes. Nonetheless, Goss et al. did find posterior lens radius, measured by phakometry, to be significantly correlated to vitreous chamber depth in emmetropes at $r = -0.50$, and in myopes at $r = -0.31$. Goss et al. suggested lower lens power in myopes to be an emmetropisation process, in the attempt to decrease the refractive power of the eye.

The decrease in lens thickness and power occurs as a result of axial elongation, suggesting that the crystalline lens thins in order to maintain coordinated refractive focus on the retina during axial elongation (Mutti et al., 2005; Iribarren, 2015).

It was not possible to perform cycloplegia in the present study due to the existing laws in Singapore that prevent its legal use by optometrists, possibly resulting in the variability of lens thickness observed, as participants' accommodation could still be active. As such, the weak association in the myopic groups in the present study, coupled with a small sample size in Non-Myopes, makes it difficult to confirm the phenomenon of decreasing lens thickness with increasing myopia. In addition, the study by Goss et al. (1997) was the only one that used cycloplegia, making comparisons difficult. It is also likely that the age range of participants would affect the variability of lens thickness. The study by Blanco et al. had a narrower age range with a mean of 20.32 ± 2.82 year, which is similar to the present study with a mean age of 18.14 ± 1.08. The studies by Mallen et al. and Osuobeni had a wider age range of 17 to 40, and 16 to 50, respectively, which could also make comparisons difficult, since lens thickness is known to increase with age (Wong et al., 2001; Wickremasinghe et al., 2004; Shufelt et al., 2005).

4.2.1.5. Axial Length and Vitreous Chamber Depth

Axial lengths and vitreous chamber depths correlated strongly and negatively with spherical equivalent refraction, which is an expected known finding (Wildsoet, 1999). The observed stronger correlation in Mod/High-Myopes followed by Low-Myopes, and Non-Myopes demonstrated that axial elongation results in the increase in myopia. It is clear that longer axial lengths and deeper vitreous chambers are associated with myopia (Grosvenor and Scott, 1991; Goss et al., 1997; McBrien and Adams, 1997; Llorente et al., 2004; Wickremasinghe et al., 2004; Mallen et al., 2005). It is also interesting to note that myopes with earlier onset exhibited longer axial length and vitreous chamber depth, compared to adult-onset myopes and emmetropes (Grosvenor and Scott, 1991; McBrien and Adams, 1997). Based on the consistently strong correlation between vitreous chamber depth and axial length for Non-Myopes, Low-Myopes, and Mod/High-Myopes, axial elongation can essentially be attributed to the deepening of the vitreous chamber.

4.2.1.6. Axial Length / Corneal Radius Ratio

The correlation between axial length / corneal radius (AL/CR) ratio and spherical equivalent refraction exhibited similar trends to the correlations with axial length and vitreous chamber depth, where it was strongest with Mod/High-Myopes, and weakest with Non-Myopes. The correlation coefficients had previously been shown to be stronger in patient groups with higher refractive errors (Blanco et al., 2008). Of all the various biometric parameters, AL/CR ratio had the strongest correlation to the spherical equivalent refraction, at -0.874. The correlation coefficients between refractive error and AL/CR ratio ranged from -0.670 to -0.915 in previous studies (Grosvenor and Scott, 1994; Llorente et al., 2004; Mallen et al., 2005; Osuobeni, 1999). The mean AL/CR ratio in Mod/High-Myopes in the present study was significantly higher than Low-Myopes, which was also significantly higher than Non-Myopes, and was consistent with reports from previous studies where AL/CR ratios were higher in existing myopes compared to emmetropes (McBrien and Adams, 1997; Osuobeni, 1999; Llorente et al., 2004; Blanco et al., 2008).

Grosvenor and Scott (1994) proposed the emmetropic eye to have an AL/CR ratio of 3.0, based on the axial length of 24.00 mm and corneal radius of 8.00 mm. The mean AL/CR ratio for all the participants in the present study was 3.19, and ranged from 2.91 to 3.70. Out of 13 Non-Myopes, there were only four participants with AL/CR ratios of less than 3.0. Despite an average spherical equivalent refractive error of +0.15 D (range from -0.25 D to +0.64 D), the Non-Myopes (comprising emmetropes and mild hyperopes) in this study had a slightly higher mean of 3.02. In comparison, the previously reported AL/CR ratios of emmetropes were 2.79 (Grosvenor and Scott, 1994), 2.98 (Yebra-Pimentel et al., 2004), and 2.97 (Blanco et al., 2008), all of which were investigations perform on university populations in western ethnic groups. The small sample size of 13 Non-Myopes provides room for investigation on whether adult emmetropes and hyperopes in the predominantly Chinese population Singapore exhibit higher AL/CR ratios compared to western ethnic groups.

4.2.1.7. Regression Model for Refractive Error by Ocular Biometric Parameters

The multiple linear regression model achieved a high adjusted r^2 value of 0.902, where the AL/CR ratio, anterior chamber depth, corneal radius, and lens thickness were able to account of 90.2% of the variance in the spherical equivalent refractive error. In fact, the AL/CR ratio played a major role in this model, equating to -0.18 D for every 0.01 unit change in AL/CR ratio. The multiple regression model proposed by Blanco et al. (2008) had a much lower r^2 value of 0.687. In the present model, axial length and vitreous chamber depth were not statistically significant, and were excluded from the analysis. This was due to the high correlation between AL/CR ratio and spherical equivalent refractive error, which reasonably described the major ocular component changes that brought about myopia; corneal radius and axial elongation. Regrettably, lens power was not analysed in this study, which could potentially increase the significance of this regression model.

4.2.2. Longitudinal Changes of Refractive Error and Ocular Biometry

4.2.2.1. Refractive Error Changes

The high proportion of myopes in this study highlights the gravity of the myopic epidemic that is occurring in Singapore and many East Asian and Southeast Asian cities. The percentage of myopes remained stable with 86.9 % at the baseline, and 84.1 % at the 24 month visit. Out of the 88 participants who completed the study, 79 (89.8 %) participants were optometry students with a mean age of 18.1 ± 1.1. Grosvenor and Scott (1993) investigated the change in refraction in optometry students who had a slightly older mean age of 20.4 ± 1.0 for youth-onset myopes, 22.4 ± 3.4 for adult-onset myopes and 21.4 ± 3.3 for emmetropes. The authors found youth-onset myopes to progress by -0.26 D and emmetropes to progress by -0.15 D over a period of 3 years. In Norway, the prevalence of myopia in university engineering students increased by 17 % to 65 % over three years (Kinge and Midelfart, 1999). The mean change in the Norwegian students was -0.51 D. A significant 59 % of emmetropes became myopic, and 73 % of myopes experienced progression of at least 0.37 D. This alarming increase and shift towards myopia was suggested to be attributed to intensive near work and academic pressures (Kinge et al., 2000). In a three year longitudinal study on university science students in Portugal, Jorge et al. (2007b) described the increase of myopia prevalence by 5.1 %, stemming from the mean change of refraction by -0.29 D.

A number of studies have examined the refractive change in medicine students, due to the intensive nature of medical studies. Lin et al. (1996) reported significant progression of myopia by -0.54 D and -0.70 D for Chinese male and female Taiwanese medical students, respectively, over five years. Caucasian medical students in Denmark exhibited an increase in the prevalence of myopia by 5.7 % to 42.7 %, with a significant mean change of -0.25 D over two years (Jacobsen et al., 2008). A more recent study by Lv and Zhang (2013) found the prevalence of myopia in Chinese medical students to increase by 5.6 % to 84.1 % over two years. The mean change of refraction was -0.32 D. Lv and Zhang reported that all participants including myopes, hyperopes and emmetropes exhibited negative change in refraction, where the largest change were from high and moderate myopes. Medical students who originated from rural areas were also found to have more negative change compared to those from urban environments. On the contrary, a Turkey study found no change of refraction in medical students over the course of one year (Onal et al., 2007).

In the present study, eight (9.1 %) participants exhibited significant increases in myopia of at least SE -0.37 D. Out of these eight participants, six were already myopic at the baseline visit. The remaining two participants were Non-Myopes, and were still categorised as Non-Myopes despite their slight increase of myopia. As such, there was no overall increase in the proportion of myopic participants, which contrasts from the findings of previous studies that reported increase in myopic prevalence (Lin et al., 1996; Kinge et al., 1999; Kinge and Midelfart, 1999; Jorge et al., 2007; Lv and Zhang, 2013). The mean baseline refractive error in this study was SE -3.05 ± 2.39 D, which was significantly higher than Portuguese and Norwegian university students at SE +0.04 ± 1.49 D and SE -0.64 ± 2.18 D, respectively. It is also worthy to note that Taiwanese medicine students exhibited a higher mean baseline refractive error, at SE -4.26 ± 2.66, while medicine students at Wen Zhou, China had slightly lower mean baseline refractive error at SE -2.52 ± 2.13 D. The positive mean difference between the 24 month visit and the baseline of +0.14 D highlights the possibility that participants accommodated more during the subjective refraction at the baseline visit. This phenomenon did not appear to be specific for a particular refractive error group, but was more pronounced in moderate and higher myopes. Tonic accommodation had been shown to be present in emmetropes, early-onset myopes and late-onset myopes, and that high myopes tended to exhibit greater amounts of tonic accommodation (Fisher et al., 1987).

Unfortunately, participants in the present study did not undergo cycloplegia due to existing laws prohibiting its use by optometrists in Singapore. The possibility that participants were performing visual tasks prior to subjective refraction also cannot be excluded, possibly increasing tonic accommodation. Despite that, the fogging technique was used to reduce the likelihood of participants accommodating during subjective refraction. Inevitably, the accommodation in some participants could not be fully relaxed during subjective refraction, resulting in more negative refractions. Participants, especially optometry students, could have become accustomed to the subjective refraction process, where the fogging technique tended to be more successful in relaxing their accommodation in subsequent visits.

Youth-onset myopia commences at the age of six (Grosvenor, 1987), and had been shown to cease earlier for females, between 14.4 and 15.3 years of age, and later for males, between 15.0 and 16.7 years of age (Goss and Winkler, 1983). The majority of participants in the present study were youth-onset myopes, as 93.3 % of those who completed the study reported an initial refractive correction age of younger than 16, out of which, only two participants started wearing spectacles younger than 6 years of age. The age of all participants in the present study ranged from 16 to 22 years, which was at the upper age limit of cessation of myopic growth as reported by Goss and Winkler. As such, no further increase in myopia progression should be expected in this study. The two-year follow-up period of this study was intended to reveal the longitudinal changes, if any, as Onal et al. (2007) found no significant changes in their one-year longitudinal study. However, the absence of myopia progression in pre-university tertiary students in the current study highlights the distinctions from the majority of studies conducted on university students.

Kinge et al. (2000) proposed the effect of intensive near work to be associated with the progression of myopia in university students, where the reading of scientific literature and attending lectures were negatively correlated with refractive error, but not studying for examinations, using computers, or general reading. However, it is of the current author’s experience that polytechnic students in Singapore are not required to read scientific journals on a regular basis, and that studying was typically only in preparation for an upcoming test or examination. In addition, polytechnic students in Singapore no longer attend tuition classes that are widespread in primary and secondary school levels and known to be associated with myopia development (Saw et al., 2001b; Morgan and Rose, 2013). In the present study, the participants may not be under substantial academic pressures where intense reading and heightened attentiveness were required to keep up to the progress of schoolwork, in contrast to university students. In fact, there may be lesser academic pressures compared to primary and secondary school students, as parents no longer send them to additional tuition class outside of school (Saw et al., 2001b; Davie, 2015).

Since there has yet to be a longitudinal study to investigate the changes in refraction of university students in Singapore, it is not known if the high academic pressures in university would indeed cause myopic progression that parallels the previous studies discussed above. The link between the lifestyle of university students and their myopic progression would need to be examined in detail. In addition, future studies that investigate the differences in academic pressures between polytechnic, university, secondary, and primary school educations could also shed light on how they affect myopic changes.

4.2.2.2. Ocular Biometric Changes

Ocular biometry measurements using the Lenstar LS900 were able to mitigate the limitations of non-cycloplegic refraction findings. All the ocular components remained unchanged over the 24 month period, with the exception of lens thickness and axial length. The constancy of corneal radius and thickness was a known finding where previous studies had found the cornea to be of minimal role in ametropic changes (Kinge et al., 1999; Saw et al., 2005a; Davis et al., 2005; Jorge et al., 2007; Onal et al., 2007;

Jacobsen et al., 2008). As discussed in section 4.2.1.2, the corneal radius flattens with ocular growth (Sorsby, 1956), but could steepen with drastic increases in axial lengths (van Alphen, 1961; Sorsby and Leary, 1968).

The crystalline lens was notably thicker in the 12 month and 24 month visits compared to the baseline. This increase in lens thickness was also evident when analysing within each refractive group. Jorge et al. (2007b) had also reported the increase of lens thickness over three years in Portuguese university students, which also exhibited statistically significant increase in axial length. Similarly, Kinge et al. (1999) reported increase in lens thickness across different refractive error types, which was attributed to age related changes. Onal et al. (2007) observed a non-significant increase in lens thickness of medical students in Turkey over a year, but attributed it to variability as a result of accommodation. On the contrary, McBrien and Adams (1997) reported mild but significant thinning of the crystalline lens in myopic eyes. The multiple regression analysis revealed that the anterior chamber depth exhibited the most significant relationship with lens thickness, which explains the thickening of the crystalline lens taking up space in the anterior chamber. The crystalline lens thickness has been shown to increase with age, where a mean thickening of between 10 and 21 μm a year (Shufelt et al., 2005; Richdale et al., 2008), and between 0.18 and 0.34 mm every decade (Wong et al., 2001). Since cycloplegia was not performed in this study, it is difficult to determine if crystalline lens thickening had indeed taken place as the role of accommodative fluctuation cannot be dismissed. However, a more likely explanation was that there was a significant increase in lens thickness by 0.04 mm (40 μm) over 24 months due to normal lens growth, which was in agreement with the findings of previous studies.

The small but statistically significant higher axial length on the 24 month visit compared to baseline suggests the occurrence of axial elongation by only 0.02 mm. When the participants were grouped according to refractive error, Mod/High-Myopes appear to exhibit more axial elongation than Non-Myopes and Low-Myopes, which was however not statistically significant. Moreover, the increase in axial length was also not statistically significant within each refractive error group. Kinge et al. (1999) found increasing axial length in tandem with the change towards more negative refractive errors in Norwegian university students over three years. Studies conducted on Chinese, Portuguese, and Danish medical students reported axial elongation as the main mechanism that brought about refractive error change (Lin et al., 1996; Jorge et al., 2007; Jacobsen et al., 2008). McBrien and Adams (1997) indicated that the vitreous chamber depth elongation was the main mechanism that brought about axial elongation, which was in agreement with the findings by Grosvenor and Scott (1993). The findings from the multiple regression analysis were also in agreement, revealing that vitreous chamber depth was the most significant component that affects the change in axial length.

The AL/CR ratio remained constant through the course of 24 months, with no change between and within each refractive error group. Since AL/CR was highly correlated with refractive error, where AL/CR explained up to 86.5 % of the variance of refractive error (Llorente et al., 2004), AL/CR ratio can be aptly used to monitor ocular biometric myopic changes. The present study appears to be the first that described the use of AL/CR data in the monitoring of myopia progression. As AL/CR takes into account the refractive power of the cornea in relation to the axial length, AL/CR could be more specific towards identifying true axial elongation from normal ocular growth, which is especially useful in monitoring children. Thus, future research is recommended to examine the role of AL/CR in the monitoring of myopic axial elongation.

4.2.3. Summary

The ocular biometric parameters obtained were in agreement with previous studies. The relationship between corneal radius and axial length was the strongest in emmetropes, which became weaker with axial elongation. Corneal thickness was independent of myopic axial growth, while anterior chamber depth appear to increase with axial elongation. Crystalline lens thickness was negatively correlated with axial length that became weaker with higher magnitudes of myopia. The deepening of the vitreous chamber was the main component of axial elongation to cause myopia progression. The AL/CR ratio was strongly correlated to the spherical equivalent refractive error, and may be a useful parameter for monitoring and comparing between patients.

The completion rate for the 24 month visit was high, at 88.9 %, which provided adequate longitudinal data for analysis. The prevalence of myopia in this cohort of young adults remained stable and did not increase over the 24 month period, at 86.9 % during the baseline visit, and 84.1 % at the 24 month visit, which was in contrary to previous studies which reported between 5.1 % and 17.0 % increase in prevalence rates. This was postulated to be due to lesser academic pressures at the polytechnic in Singapore compared to university studies. Ocular biometric studies revealed minimal axial elongation of 0.02 mm, and crystalline lens thickening of 0.04 mm over 24 months. While the minimal axial elongation was likely to be of little clinical significance, the slightly higher, though not statistically significant, mean change of axial length in Mod/High-Myopes suggest that higher myopes potentially may exhibit more elongation compared to lesser myopes. The lens thickening was likely due to age-related changes, or variability as a result of the non-usage of cycloplegia.

With the high prevalence of myopia in this sample of young adults, it is important to understand the impact of refractive error on the overall well-being of a patient. The usage of refractive correction, the visual quality, the psycho-sociological effect, as well as the limitation in performing activities or tasks could adversely affect patients with refractive errors. As such, the next chapter will examine the vision-related quality of life in Singapore young adults.

Chapter 5: Vision-related Quality of Life in Singapore Young Adults

In this chapter, the vision-related quality of life (VRQOL) will be examined for this sample of Singapore young adults who were students of a post-secondary tertiary education institution. The previous literature on VRQOL has been discussed in Chapter 1.4, while the procedures of using the NEI-RQL-42 in this study has been described in Chapter 2.7. From the baseline data, VRQOL will be compared between Non-Myopes, Low-Myopes, and Mod/High-Myopes. In addition, the differences in VRQOL will also be reported between Spectacle-Wearers, Non-Wearers, and Contact Lens Mixed-Wearers. An important aspect of this chapter is the longitudinal analysis of VRQOL for all participants, as well as the comparison of VRQOL changes between the three refractive error groups. With the exception of the studies that employed the time trade-off and standard gamble methods (Saw et al., 2003; Lim et al., 2005), no other study has previously reported VRQOL data on young adults in Singapore using Likert scale instruments. This is also the first study to investigate longitudinal change in VRQOL.

5.1. Results

5.1.1. VRQOL Between Different Refractive Groups

Vision-Related Quality of Life (VRQOL) using the NEI-RQL-42 instrument was compared between Non-Myopes (n = 18), Low-Myopes (n = 40), and Mod/High-Myopes (n = 41) at the baseline visit (Table 5.1). Statistically significant differences in VRQOL scores were observed in the Clarity of Vision ($\chi^2(2) = 8.98$, $p < 0.001$), Expectations ($\chi^2(2) = 29.65$, $p < 0.001$), Near Vision ($\chi^2(2) = 13.77$, $p < 0.001$), Activity Limitations ($\chi^2(2) = 31.59$, $p < 0.001$), Dependence on Correction ($\chi^2(2) = 44.71$, $p < 0.001$), Worry ($\chi^2(2) = 6.77$, $p < 0.001$), Appearance ($\chi^2(2) = 15.80$, $p < 0.001$), Satisfaction in Correction ($\chi^2(2) = 10.85$, $p < 0.001$), and the Global Score ($\chi^2(2) = 34.70$, $p < 0.001$).

A post-hoc analysis was performed using the Mann-Whitney U test with manual Bonferroni Type I error adjustments. Non-Myopes were found to exhibit higher VRQOL scores in the Expectations ($p < 0.001$), Near Vision ($p = 0.013$), Activity limitations ($p = 0.022$), Appearance ($p = 0.001$), and the Satisfaction with Correction ($p = 0.007$) subscales compared to Low-Myopes. Non-Myopes also had higher VRQOL scores compared to Mod/High-Myopes in the Clarity of Vision ($p = 0.03$), Expectations ($p < 0.001$), Near Vision ($p = 0.001$), Activity Limitations ($p < 0.001$), Dependence on Correction ($p < 0.001$), Appearance ($p < 0.001$), and the Satisfaction with Correction ($p = 0.01$) subscales. Mod/High-Myopes experienced poorer VRQOL than Low-Myopes in the Expectations ($p = 0.042$), Activity Limitations ($p < 0.001$), and the Dependence on Correction ($p < 0.001$) subscales. When comparing the Global Score, Non-Myopes, Low-Myopes and Mod/High-Myopes were all significantly different from one another (Non-Myopes vs. Low-Myopes, $p = 0.003$; Non-Myopes vs. Mod/High-Myopes $p < 0.001$; Low-Myopes vs. Mod/High-Myopes, $p < 0.001$).

5.1.2. VRQOL Between Different Correction Groups

There were 50 participants in the Spectacle-Wearers group and 30 participants in the Non-Wearers group. The remaining participants were contact lens wearers of varying amounts of usage, and were allocated to the Contact Lens Mixed-Wearers group (CLM-wearers, n = 19). The VRQOL scores for all 13 subscales were compared between Spectacle-Wearers, CLM-Wearers, and Non-Wearers at the baseline visit (Table 5.2). Significant differences in VRQOL scores were found in the Clarity of Vision ($p = 0.014$), Expectations ($p < 0.001$), Activity Limitations ($P < 0.001$), Glare ($p = 0.035$), Dependence on Correction ($p < 0.001$), Appearance ($p = 0.01$), and Satisfaction with Correction ($p = 0.009$) subscales, as well as the Global Score ($p < 0.001$).

Post-hoc pairwise analysis was performed with Bonferroni adjustments to eliminate Type I errors, where Spectacle-Wearers were found to exhibit significantly higher VRQOL scores in the Clarity of Vision ($p = 0.021$) subscale compared to CLM-Wearers. Spectacle-Wearers, on the other hand, scored poorer in the Expectations ($p < 0.001$), Activity Limitations ($p < 0.001$), Dependence on Correction ($p < 0.001$), and Appearance ($p = 0.018$) subscales compared to Non-Wearers. Non-Wearers had higher VRQOL scores compared to CLM-wearers in the Clarity of Vision ($p = 0.031$), Expectations ($p < 0.001$), Activity Limitations ($p < 0.001$), Glare ($p = 0.04$), Dependence on Correction ($p < 0.001$), Appearance ($p = 0.036$), and Satisfaction with Correction ($p = 0.02$) subscales. In terms of the Global VRQOL score, Spectacle-Wearers and CLM-Wearers had significantly poorer VRQOL scores compared to Non-Wearers ($p < 0.001$).

	Non-Myopes (A) (n = 18)	Low-Myopes (B) (n = 40)	Mod/High-Myopes (C) (n = 41)	Sig.	Pairwise Comparisons
Clarity of Vision	92.83 ± 10.98	90.99 ± 10.37	81.05 ± 20.12	p = 0.011	A>C*
Expectations	88.89 ± 21.39	50.00 ± 31.52	32.93 ± 32.81	p < 0.001	A>B§, B>C*, A>C§
Near Vision	97.80 ± 3.88	91.77 ± 8.42	87.08 ± 12.52	p = 0.001	A>B*, A>C#
Far Vision	92.19 ± 7.04	91.17 ± 10.81	86.79 ± 14.39	p = 0.286	
Diurnal Fluctuations	83.80 ± 16.84	83.96 ± 16.03	79.88 ± 18.47	p = 0.545	
Activity Limitations	99.31 ± 2.95	93.13 ± 12.88	77.44 ± 25.27	p < 0.001	A>B*, B>C§, A>C§
Glare	88.89 ± 17.09	86.56 ± 17.31	80.49 ± 22.02	p = 0.307	
Symptoms	73.41 ± 11.89	75.09 ± 15.50	72.04 ± 17.31	p = 0.781	
Dependence on Correction	100.00 ± 0.00	85.83 ± 27.16	32.52 ± 42.61	p < 0.001	B>C§, A>C§
Worry	66.67 ± 24.09	69.06 ± 18.12	54.88 ± 25.29	p = 0.034	
Suboptimal Correction	96.53 ± 8.36	89.69 ± 14.40	85.06 ± 20.00	p = 0.051	
Appearance	88.52 ± 23.52	64.67 ± 29.74	64.88 ± 29.47	p < 0.001	A>B#, A>C§
Satisfaction with Correction	92.22 ± 19.96	80.00 ± 15.69	81.46 ± 12.95	p = 0.004	A>B#, A>C*
Global Score	89.31 ± 7.19	80.92 ± 9.09	70.50 ± 11.70	p < 0.001	A>B#, B>C§, A>C§

*p < 0.05, #p < 0.01, §p < 0.001

Table 5.1 VRQOL scores (mean ± standard deviation) between different refractive error groups at the baseline visit (n = 99).

	Spectacle-Wearers (A) (n = 50)	Contact Lens Mixed-Wearers (B) (n = 19)	Non-Wearers (C) (n = 30)	Sig.	Pairwise Comparisons
Clarity of Vision	90.04 ± 12.70	74.56 ± 23.13	90.49 ± 11.51	p = 0.014	A>B*, B<C*
Expectations	40.5 ± 34.59	30.26 ± 25.79	78.33 ± 27.65	p < 0.001	A<C§, B<C§
Near Vision	89.32 ± 11.75	89.69 ± 9.73	94.38 ± 7.87	p = 0.079	
Far Vision	87.17 ± 15.00	92.11 ± 7.71	91.87 ± 7.32	p = 0.572	
Diurnal Fluctuations	79.83 ± 17.9	80.04 ± 17.44	87.64 ± 14.90	p = 0.112	
Activity Limitations	83.13 ± 21.36	83.22 ± 25.6	98.33 ± 6.13	p < 0.001	A<C§, B<C§
Glare	83.25 ± 19.33	76.97 ± 23.30	91.25 ± 15.10	p = 0.035	B<C*
Symptoms	73.43 ± 16.61	70.86 ± 15.72	75.36 ± 14.08	p = 0.761	
Dependence on Correction	49.17 ± 46.08	63.6 ± 42.60	96.67 ± 12.69	p < 0.001	A<C§, B<C§
Worry	60.5 ± 25.30	58.55 ± 19.12	69.17 ± 20.43	p = 0.192	
Suboptimal Correction	87.25 ± 18.64	86.18 ± 17.63	93.75 ± 10.76	p = 0.226	
Appearance	64.67 ± 28.89	64.91 ± 31.80	79.11 ± 28.49	p = 0.01	A<C*, B<C*
Satisfaction with Correction	81.2 ± 14.80	77.89 ± 11.34	88.67 ± 15.48	p = 0.009	B<C*
Global Score	74.57 ± 11.96	72.99 ± 10.09	87.31 ± 8.35	p < 0.001	A<C§, B<C§

*P < 0.05, §P < 0.001

Table 5.2 VRQOL scores (mean ± standard deviation) between different refractive correction groups (n = 99).

5.1.3. Factors Contributing to VRQOL

To analyse the effect of the possible contributory factors to VRQOL, multiple regression analyses were performed, where the male gender, right spherical equivalent refractive error, spectacles use, contact lens use, no usage of refractive correction, Dioptre-Hour per week, and sports hours per week were used as predictive variables using the stepwise method (Table 5.3). No significant associations were found between the predictive variables and the Far Vision, Diurnal Fluctuations, and Symptoms subscales. Refractive error was found to be the single most significant contributor for the Near Vision, Activity Limitations, Glare, Dependence on Correction, Appearance, and Satisfaction with Correction subscales, accounting for 8.8 %, 21.0 %, 4.5 %, 44.0 %, 6.6 %, and 4.3 % of their variances, respectively.

Contact lens use explained 21.4 % of the variance in the Clarity of Vision subscale score ($F(1, 97) = 27.75$, $p < 0.001$, $r^2 = 0.222$, r^2Adjusted = 0.214), where it significantly predicted change in VRQOL ($\beta = -0.472$, $p < 0.001$). For the Expectations subscale, contact lens use ($\beta = -0.221$, $p = 0.013$) and refractive error ($\beta = -0.485$, $p < 0.001$) were found to be significant predictors that were associated with 43.1 % of the variance in the Expectations subscale ($F(2, 96) = 26.33$, $p < 0.001$, $r^2 = 0.354$, r^2Adjusted = 0.431). Dioptre-Hour ($\beta = -0.225$, $p = 0.019$) and Refractive error ($\beta = 0.295$, $p = 0.002$) were significant predictors of the Worry subscale, where they predicted 12.8 % change in its variance ($F(2, 96) = 8.183$, $p = 0.001$, $r^2 = 0.146$, r^2Adjusted = 0.128). For the Suboptimal Correction subscale, male gender and refractive error were associated with 10.7 % of its variance ($F(2, 96) = 6.89$, $p = 0.02$, $r^2 = 0.126$, r^2Adjusted = 0.107), where male gender ($\beta = 0.252$, $p = 0.01$) and Refractive error ($\beta = 0.240$, $p = 0.013$) were significant predictors. Contact lens use ($\beta = -0.202$, $p = 0.015$) and refractive error ($\beta = 0.557$, $p < 0.001$) were found to be significant predictors of the Global Score, where both explained 41.3 % of its variance ($F(2, 96) = 35.43$, $p < 0.001$, $r^2 = 0.425$, r^2Adjusted = 0.413).

	Clarity of Vision $r^2 = 0.214$		Expectations $r^2 = 0.431$		Near Vision $r^2 = 0.088$		Activity Limitations $r^2 = 0.210$		Glare $r^2 = 0.045$		Dependence on Correction $r^2 = 0.440$	
	B	**p**	***B***	**p**	***B***	**p**	***B***	**p**	***B***	**p**	***B***	**p**
Male Gender	-	-	-	-	-	-	-	-	-	-	-	-
Right SE Refractive Error			0.485	0.000	0.312	0.002	0.404	<0.001	0.234	0.02	0.667	< 0.001
Spectacles Use			-	-	-	-	-	-	-	-	-	-
Contact Lens Use	-0.472	<0.001	-0.221	0.013	-	-	-	-	-	-	-	-
No Use of Refractive Correction	-	-	-	-	-	-	-	-	-	-	-	-
Dioptre-Hour per week	-	-	-	-	-	-	-	-	-	-	-	-
Sports per week	-	-	-	-	-	-	-	-	-	-	-	-

	Worry $r^2 = 0.128$		Suboptimal Correction $r^2 = 0.107$		Appearance $r^2 = 0.066$		Satisfaction with Correction $r^2 = 0.043$		Global score $r^2 = 0.413$	
	B	**p**	***B***	**p**	***B***	**p**	***B***	**p**	***B***	**p**
Male Gender	-	-	0.252	0.010	-	-	-	-	-	-
Right SE Refractive Error	0.295	0.002	0.240	0.013	0.274	0.006	0.229	0.022	0.557	0.000
Spectacles Use	-	-	-	-	-	-	-	-	-	-
Contact Lens Use	-	-	-	-	-	-	-	-	-0.202	0.015
No Use of Refractive Correction	-	-	-	-	-	-	-	-	-	-
Dioptre Hour per week	-0.225	0.019	-	-	-	-	-	-	-	-
Sports per week	-	-	-	-	-	-	-	-	-	-

Table 5.3 Multiple linear regression analysis on the predictors of the Clarity of Vision, Expectations, Near Vision, Activity Limitations, Glare, Dependence on Correction, Worry, Suboptimal Correction, Satisfaction with Correction subscales, and the Global Score.

5.1.4. Longitudinal Change in VRQOL

The VRQOL scores of participants who completed the 24 month study (n = 88) were analysed with the Friedman test to investigate if there was any change in their VRQOL between the baseline visit, 12 month visit, and the 24 month visit. Statistically significant differences were found between the three visits in the Diurnal Fluctuations ($\chi^2(2) = 7.216$, $p = 0.027$) and the Glare subscales ($\chi^2(2) = 6.276$, $p = 0.043$) (Table 5.4). No significant differences in VRQOL scores between the three visits were present for the other 11 subscales, or for the Global Score. Post-hoc analysis with Bonferroni corrections revealed that only the 24 month score for Glare (Wilcoxon Signed Ranks Test, $Z = -2.769$, $p = 0.006$) subscale was significantly lower than the 12 month scores, which however, was not different from the baseline scores.

When the mean differences between the baseline scores and the 24 month visit scores were analysed between Non-Myopes, Low-Myopes and Mod/High-Myopes using the Kruskal Wallis Test, no significant differences were found in 12 out of the 13 subscales, or in the Global Score (Table 5.5). The mean change in VRQOL scores between the three refractive error groups was significantly different in the Dependence in Correction subscale (Kruskal Wallis Test, ($\chi^2(2) = 13.279$, $p = 0.001$). Post-hoc analysis with Bonferroni considerations found Mod/High-Myopes to have significantly positive changes compared to Low-Myopes (Mann-Whitney U Test, $Z = -3.286$, $p = 0.001$). A closer examination of the Mod/High-Myope groups revealed 17 (45.9 %) participants reported an increase in contact lens usage (Table 5.6). However, there was no significant differences in the mean change of the Dependence on Correction subscale VRQOL scores between those who reported increase, those who reported no change, and those who reported decrease in contact lens wear (Kruskal Wallis Test, ($\chi^2(2) = 2.613$, $p = 0.271$) (Table 5.7).

By the 24 month visit, 47 participants had graduated and entered the workforce, while 35 participants were still pursuing full time studies. The mean age of those who had graduated and started working was 20.8 ± 1.0 years, while those who were still studying had a mean age of 19.7 ± 0.9 years. The difference in age between these two groups of participants was statistically significant ($Z = -4.921$, $p < 0.001$). The remaining six participants were neither working, nor studying in the polytechnic (i.e. were job-hunting, taking a break), and were not included in this analysis. There were however, no significant differences in the mean change of VRQOL scores for all 13 sub-scales between the current students and the graduates who had started working when analysed with the Mann Whitney U test (Table 5.8).

N = 88	Baseline (A)	12 Month (B)	24 Month (C)	Sig.	Pairwise Comparisons
Clarity	88.04 ± 14.51	87.27 ± 14.18	85.42 ± 18.32	P = 0.996	
Expectations	50.84 ± 35.45	49.72 ± 34.64	44.10 ± 34.34	P = 0.053	
Near Vision	90.98 ± 10.72	92.23 ± 10.51	89.77 ± 14.90	P = 0.727	
Far Vision	89.51 ± 12.32	90.45 ± 12.31	89.21 ± 16.64	P = 0.311	
Diurnal Fluctuations	81.83 ± 17.52	85.86 ± 16.64	80.33 ± 20.72	**P = 0.027**	B>C^
Activity Limitations	88.41 ± 19.39	89.26 ± 20.19	85.11 ± 24.27	P = 0.291	
Glare	83.85 ± 20.05	84.97 ± 19.14	79.21 ± 23.61	**P = 0.043**	B>C[#]
Symptoms	73.15 ± 15.89	72.59 ± 16.49	71.83 ± 17.69	P = 0.462	
Dependence on Correction	65.54 ± 43.94	73.41 ± 39.30	69.29 ± 38.08	P = 0.400	
Worry	63.90 ± 22.96	64.89 ± 24.92	63.48 ± 22.79	P = 0.891	
Suboptimal Correction	89.47 ± 16.42	89.89 ± 17.16	87.22 ± 21.97	P = 0.565	
Appearance	70.04 ± 29.83	71.99 ± 28.99	70.56 ± 29.88	P = 0.987	
Satisfaction with Correction	82.92 ± 15.24	84.94 ± 14.55	82.70 ± 16.57	P = 0.373	
Global Score	78.35 ± 12.20	79.80 ± 11.79	76.79 ± 14.94	P = 0.236	

*p < 0.05, [#]p < 0.01, ^not significant with Bonferroni corrections.

Table 5.4 VRQOL scores (mean ± standard deviation) between the baseline (A), 12 month (B), and 24 month (C) visits.

	Non-Myopes (A) (n = 15)	Low-Myopes (B) (n = 36)	Mod/High-Myopes (C) (n = 37)	Sig.	Pairwise Comparisons
24 month – Baseline Difference					
Clarity	-0.42 ± 11.63	-6.71 ± 18.13	2.93 ± 17.99	p = 0.320	
Expectations	-3.33 ± 24.76	-11.81 ± 24.99	-2.03 ± 21.55	p = 0.273	
Near Vision	-0.83 ± 6.24	-1.27 ± 11.18	1.20 ± 11.17	p = 0.551	
Far Vision	2.26 ± 8.39	0.48 ± 13.69	0.28 ± 20.63	p = 0.976	
Diurnal Fluctuations	10.28 ± 24.65	-2.89 ± 19.08	-2.25 ± 22.58	p = 0.219	
Activity Limitations	0.83 ± 3.23	-4.51 ± 18.99	-2.70 ± 22.32	p = 0.181	
Glare	0.83 ± 19.17	-3.82 ± 19.78	-5.07 ± 19.42	p = 0.676	
Symptoms	3.1 ± 13.15	-3.97 ± 15.31	1.54 ± 19.79	p = 0.135	
Dependence on Correction	-7.22 ± 25.76	-10.07 ± 20.40	21.73 ± 54.97	**p = 0.001**	A<C^, B<C[#]
Worry	7.50 ± 18.18	-3.47 ± 22.68	1.01 ± 18.95	p = 0.333	
Suboptimal Correction	2.50 ± 7.01	-0.35 ± 19.48	-3.72 ± 28.08	p = 0.576	
Appearance	-2.22 ± 33.49	8.89 ± 33.12	-5.05 ± 31.36	p = 0.138	
Satisfaction with Correction	0.00 ± 15.12	1.11 ± 19.68	0.54 ± 13.73	p = 0.976	
Global Score	1.02 ± 6.42	-2.95 ± 8.30	0.65 ± 8.37	p = 0.131	

*p < 0.05, [#]p < 0.01, ^not significant with Bonferroni corrections.

Table 5.5 Mean VRQOL changes (mean change ± standard deviation) over 24 months between Non-Myopes (A), Low-Myopes (B) and Mod/High-Myopes (C).

	Non-Myopes	Low-Myopes	Mod/High-Myopes	Sig.
Spectacles Use				
Mean Change	6.13	-5.86	-4.11	NS
No Change (n)	11 (73.3)	11 (30.6)	10 (27.0)	
Increase (n)	2 (13.3)	9 (25.5)	10 (27.0)	
Decrease (n)	2 (13.3)	16 (44.4)	17 (45.9)	
Contact Lens Use				
Mean Change	0.80	5.06	3.81	NS
No Change (n)	12 (80.0)	13 (36.1)	10 (27.0)	
Increase (n)	1 (6.7)	14 (38.9)	17 (45.9)	
Decrease (n)	2 (13.3)	9 (36.1)	10 (27.0)	
No Use of Correction				
Mean Change	-6.93	0.47	-0.92	NS
No Change (n)	10 (66.7)	14 (38.9)	17 (45.9)	
Increase (n) (n)	2 (13.3)	13 (36.1)	10 (27.0)	
Decrease	3 (20.0)	9 (16.7)	10 (27.0)	

Table 5.6 Mean change in usage of various refractive correction modes according to difference refractive groups (n = 88). NS denotes non-statistical significance.

	No Change in CL Wear (n = 10)	**Increase in CL Wear** (n = 17)	**Decrease in CL Wear** (n = 10)	**Sig.**
Mean Change in Dependence on Correction VRQOL Scores	36.67 ± 67.50	8.09 ± 57.21	30.00 ± 32.20	p = 0.271

Table 5.7 Comparison of mean change of Dependence on Correction subscale scores (mean change ± standard deviation) between Baseline and the 24 month visits in Mod/High-Myopes, according to the reported change in contact lens wear (n = 37).

	Students[A] (n = 35)	Working Graduates[B] (n = 47)	Sig.
24 month – Baseline Difference			
Clarity	-1.67 ± 16.86	-0.71 ± 14.89	p = 0.740
Expectations	-4.29 ± 25.35	-6.38 ± 23.00	p = 0.763
NearVision	0.67 ± 12.40	-1.06 ± 9.28	p = 0.351
FarVision	-1.16 ± 19.37	1.45 ± 14.51	p = 0.267
Diurnal Fluctuations	-4.17 ± 22.78	2.48 ± 21.85	p = 0.201
Activity Limitations	-5.36 ± 16.89	-0.93 ± 19.98	p = 0.326
Glare	-5.00 ± 18.49	-3.19 ± 18.33	p = 0.603
Symptoms	-1.22 ± 18.13	-0.84 ± 16.01	p = 0.888
Dependence on Correction	4.41 ± 49.35	4.26 ± 37.59	p = 0.948
Worry	2.86 ± 19.90	0.53 ± 20.68	p = 0.789
Suboptimal Correction	-2.86 ± 19.9	-1.06 ± 22.55	p = 0.356
Appearance	0.57 ± 31.24	1.28 ± 34.74	p = 0.807
Satisfaction with Correction	-1.71 ± 17.74	1.70 ± 14.94	p = 0.762
Global Score	-1.46 ± 8.64	-0.19 ± 7.40	p = 0.527

Table 5.8 Comparisons of mean VRQOL score changes (mean change ± standard deviation) between current students and graduates who had started working.

5.2. Discussion

This section will discuss the vision-related quality of life (VRQOL) differences between Non-Myopes, Low-Myopes, and Mod/High-Myopes, and between Spectacle-Wearers, Contact Lens Mixed-Wearers, and Non-Wearers, and compare the current findings with previous studies. Previous research had not analysed the major factors that contribute to VRQOL, which when identified, may allow insights into how VRQOL can be clinically improved. As such, the factors that contribute to VRQOL, particularly refractive error, eyewear usage, gender, and near work will be evaluated. As this is the first study to investigate the longitudinal changes of VRQOL using Likert instruments, this section will examine the VRQOL data that was obtained in this sample of Singapore young adults.

5.2.1. VRQOL Between Refractive Error Groups

Myopes (both Low-Myopes and Mod/High-Myopes) had overall poorer VRQOL compared to Non-Myopes. Myopes expected changes in their vision for the better, had poorer quality of near vision, more limitations of activities due to vision or correction, were less satisfied with their appearance due to their eyewear, and were less satisfied with their overall vision and correction status. Mod/High-Myopes had more clarity and visual symptoms compared to Non-Myopes, and were also more dependent on their correction for reading as well as driving. Comparing the two groups of myopes, Mod/High-Myopes expected more changes in their vision for the better compared to Low-Myopes, and were more limited in their activities and (as may be expected) more dependent on their vision correction for reading and driving. Overall, Mod/High-Myopes had the poorest VRQOL, followed by Low-Myopes, while Non-Myopes had the best VRQOL.

Despite the use of refractive correction, myopes do suffer from VRQOL issues, which agrees with the findings of Rose et al. (2000) who used the subjective visual function (VF-14) and vision related quality of life (VQOL) questionnaires to investigate adult patients with low, moderate, and high degrees of myopia. Hays et al. (2003) employed an earlier version of the NEI-RQL survey in a multi-centre study, and reported significantly poorer VRQOL scores in 667 myopes when compared to 114 emmetropes for all but the Appearance subscale. Hays et al. also found poorer VRQOL in higher myopes, particularly in the Expectations, Activity Limitations, Dependence on Correction, and Worry, which was similar to the present study. In a cross-sectional survey that used the Vision Quality of Life Index, Chen et al. (2007) reported that myopes had more concerns with visual functions. A more recent study that used the Iranian version of the NEI-RQL-42 instrument reported significantly higher VRQOL scores in emmetropes for all 13 subscales compared to myopes (Pakpour et al., 2013). Studies that used the time trade-off and the standard gamble method of evaluating quality of life between myopes did not find any differences between different severity of myopia (Saw et al., 2003; Lim et al., 2005).

Likert-scale instruments, such as the NEI-RQL-42, appear to be more useful than time trade-off and standard gamble instruments in assessing VRQOL. In the present study, the NEI-RQL-42 instrument was able to demonstrate the VRQOL differences between participants with differing degrees of refraction. Myopes suffered from significantly poorer VRQOL than Non-Myopes, where higher myopes were worse off than low myopes. With the increasing magnitudes of myopia in patients, clinicians need to be concerned with, and address, the issues of the higher expectations in their refractive correction, the potential limitations in participating in certain activities due to their eyesight, and the greater dependence on their refractive correction.

5.2.2. VRQOL Between Refractive Correction Groups

Spectacle-Wearers had higher expectations for their vision to change for the better compared to Non-wearers. In addition, they were more limited in the activities that they can perform, more dependent on their vision correction to read and drive, and were less satisfied with their appearance with their eyewear. Contact Lens Mixed-Wearers (CLM-Wearers) reported poorer visual clarity than Spectacle-Wearers. Comparing to Non-Wearers, CLM-Wearers had poorer visual clarity, greater expectations for their vision to change for the better, increased limitations on the activities they can perform, suffered more from glare, were more dependent on their vision correction to read and drive, less satisfied with their appearance with vision correction, and were overall less satisfied with their vision and correction status. As a whole, Spectacle-Wearers and CLM-Wearers had significantly lower VRQOL compared to Non-Wearers.

Queirós et al. (2012) utilised the Portuguese version of the NEI-RQL-42 questionnaire on randomly selected patients at an ophthalmology clinic and reported that contact lens wearers exhibited poorer VRQOL scores in the Diurnal Fluctuations and Worry subscales, but had higher VRQOL scores in the appearance subscale compared to spectacle wearers. The authors also found no significant difference in the Global score between contact lens wearers and spectacle wearers, and that emmetropes had higher VRQOL scores than spectacle wearers and contact lens wearers in 11 out of 13 subscales. Walline et al. (2000) reported no significant differences in visual function scores between spectacle wearers, rigid contact lens wearers and soft contact lens wearers in 10 out of 12 subscales of the National Eye Institute Visual Function Questionnaire (NEI-VFQ), where spectacle wearers had lower scores only in the Peripheral Vision subscale compared to soft contact lens wearers. In the present study, Non-Wearers had higher VRQOL in only four subscales compared to Spectacle-Wearers, and in only seven subscales compared to CLM-Wearers. There was also only a significant difference in the Clarity of Vision subscale between Spectacle-Wearers and CLM-Wearers, which is largely in agreement with the findings by Queirós et al. and Walline et al., as there was also no significant difference in the Global Score between Spectacle-Wearers and CLM-Wearers.

Conversely, (Pesudovs et al., 2006) reported significantly better VRQOL scores in contact lens wearers compared to spectacle wearers with the QIRC questionnaire.

The findings from the present and previous studies highlight the similarities in the level of VRQOL experienced by contact lens wearers and spectacle wearers. The minor differences between contact lens wearers and spectacle wearers were likely due to the unique features of each type of correction, as spectacle wearers are more likely to have stable and clearer vision. Contact lens wearers, on the other hand, could suffer from lens desiccation, deposits, and residual cylinders as a result of inappropriate correction or toric lens instability. Although CLM-Wearers in this study might not have used contact lenses during all of their waking hours, all of them were contact lens users. CLM-wearers also did not use spectacles during most of their waking hours, but still on relied on some form of vision correction most of the time. It appears that the use of contact lenses does not drastically improve the VRQOL beyond that of spectacles. In this study, CLM-Wearers had more VRQOL subscales that were poorer than Non-Wearers compared to Spectacle-Wearers, although the Global Scores were similar. It can be conceived that the use of contact lenses did not enhance the lifestyle and quality of life in this sample young adults, who might still be quite accustomed to spectacle corrections. It can also be suggested that contact lens wearers were more critical of their vision and less accepting of visual imperfections, as CLM-Wearers exhibited lower, although statistically insignificant, Expectations subscale score compared to Spectacle-Wearers.

5.2.3. Factors Contributing Towards VRQOL

The significant relationship between myopia and VRQOL has been established in section 5.2.1, where higher myopes exhibited poorer VRQOL, and Non-Myopes had the highest VRQOL. Since myopes require refractive correction, where higher myopes are more likely to be dependent on them, the use of refractive correction could be a cause of the lower

VRQOL scores in myopes. The multiple linear regression analysis included the possible predictors that could contribute towards the VRQOL scores of each subscale. The refractive error was the most significant predictor of VRQOL in six subscales, where the use of refractive correction was not a significant factor towards poorer VRQOL. Since there were no hyperopic participants above SE +0.75 D, negative refractive error was the main reason for participants who experienced less desirable near vision, were limited in participating in certain activities, suffered from glare, felt dependent on their correction, and were less satisfied with their appearance and their correction.

Contact lens use significantly reduced VRQOL under the Clarity of Vision subscale, which could be explained by the desiccation, deposits, or inappropriate correction of soft contact lenses in the eye, resulting in the reduction of visual acuity. The amount of refractive error did not appear to affect visual clarity. Participants who felt that their vision could be better, were affected by higher myopia as well as the use of contact lenses. Greater amounts of time spent on reading were associated with participants worrying about their vision, in addition to having higher myopia. Males were less concerned about wearing corrections that were less comfortable, and females appeared to be more concerned about the appropriateness of their refractive correction. Overall, negative refractive error remains the main determinant of poorer VRQOL in participants, where contact lens use also played a significant but lesser role in reducing the VRQOL. It is interesting to note that the use of spectacles was not implicated in causing any change in VRQOL.

To the knowledge of the author, there has not been any previous research that has examined the contributory factors towards VRQOL scores. Myopes have been shown to exhibit significantly lower VRQOL (Rose et al., 2000; Queirós et al., 2012; Pakpour et al., 2013). Spectacles and contact lens wear have been found to be associated with lower VRQOL scores (Walline et al., 2000; Queirós et al., 2012), where spectacle wear was suggested to be worse (Pesudovs et al., 2006). In the present study, contact lens wear was the second most significant contributor to poorer VRQOL. Contact lens wear in this student population did not appear to have gained traction, as they were exposed to these devices, and yet had not developed a reliance on them as a major mode of vision correction. These young adult contact lens users likely felt that contact lenses were not able to meet their expectations and had poorer quality of vision. Since the majority of the participants were optometry students, it was also possible that they accepted contact lens wear as part of their training, and were not actively seeking its use as a form of refractive correction. As such, the participants did not consider contact lens wear as a favourable mode of refractive correction.

This study did not investigate the appropriateness of the refractive correction that the participants used, where contact lenses may not be providing participants with the level of vision achieved with spectacles. Refractive astigmatism might not be fully corrected, where the participants may instead be corrected with spherical equivalents (Kruse and Løfstrøm, 1996; Cho et al., 2012; Morgan et al., 2013). While majority of the participants used spectacles most of the time during their waking hours, it did not adversely influence VRQOL.

5.2.4. Longitudinal Changes in VRQOL

Previous research that investigated the associations between the quality of vison and the quality of life were mainly cross-sectional in design. Research of this nature is less challenging logistically and relatively inexpensive to conduct. Longitudinal studies to investigate the change in quality of life have been performed to monitor the effect of diabetes and also in cancer studies (Grandy and Fox, 2012; Koch et al., 2013; Lyon et al., 2014; Alva et al., 2014; Holtzer-Goor et al., 2015), but not in the domain of vision-related quality of life. The present study was the first longitudinal research performed to investigate the change in VRQOL. Longitudinal studies are able to identify the factors that contribute towards the change in quality of life, if any occurs. While it has been established that VRQOL is poorer for higher myopes and contact lens wearers in this study, it is not yet known if there will be any further change in VRQOL scores with time. If VRQOL is established to be stable over a period of time, it can be conceived that any intervention to improve VRQOL, such as contact lenses or refractive surgery, would be sustained.

5.2.4.1. Longitudinal Changes in Overall VRQOL

It has been established earlier in Section 5.2.2 that Mod/High-Myopes exhibit poorer VRQOL than Low-Myopes, who in turn have poorer VRQOL than Non-Myopes. While refraction remained stable for this sample of participants (Section 4.1.3), it is not known if VRQOL improves over time due to adaptation. The possibility of VRQOL worsening over time also exists, as the accumulation of the poorer visual function and quality may occur. From the analysis of all 88 participants who completed the study, there were no significant changes in VRQOL for 11 subscales. Participants also did not experience any overall change in their VRQOL, as the Global scores over the three visits were similar. The exception was for the Diurnal Fluctuations and Glare subscales, where both subscales exhibited higher scores for the 12 month visits compared to the 24 month visits. However, there were no differences between the baseline and 24 month visit. As such, VRQOL do not change over time over a span of 24 months in this cohort of Singapore young adults.

The present study reveals that the overall VRQOL, as well as in the subscale level, is stable in young adults and does not change over a course of two years. This information, although not unexpected, confirms that VRQOL is stable and sustained over a period of at least two years. Hence, clinicians offering interventions that can potentially improve patients' VRQOL would expect the improvement to be sustained following the improvement. This study is however, not able to present VRQOL data during the onset of myopia, in order to observe the change in VRQOL as the patient transits from being emmetropic to myopic. Although such a cohort study will provide valuable and detailed data on how myopia onset affects patients in the psycho-sociological and functional aspect, it would alas be a very challenging research to conduct, due to the expense, and difficulties in recruitment and data collection. Pre-myopic children, who are difficult to identify, would have to be recruited and monitored annually for their refractive error. Children at the myopia incipient age of typically between five and 12 years would have varying levels of understanding of survey questions, which could also result in inconsistencies of data.

5.2.4.2. Changes in VRQOL Between Refractive Error Groups

The separate analysis of Non-Myopes, Low-Myopes, and Mod/High-Myopes provided the opportunity to examine the change in VRQOL that could exist within each refractive error group. A significant improvement in the Dependence on Correction subscale provided evidence that Mod/High-Myopes were less dependent on refractive correction for reading or driving at the 24 month visit compared to baseline. Although 45.9 % of participants in the Mod/High-Myopes group reported increased usage of contact lenses, they had the lowest mean change compared to those who had no change or decrease in contact lens wear. Therefore, the increase in VRQOL for the Dependence on Correction subscale cannot be attributed to the increased usage of contact lenses. It can only be speculated that Mod/High-Myopes adapted to their refractive correction. For the remaining 12 subscales, no significant differences in VRQOL change were observed between Non-Myopes, Low-Myopes, and Mod/High-Myopes. For the Global Score, the VRQOL between the three refractive error groups were also similar, suggesting no change in VRQOL over the course of 24 months in general.

5.2.4.3. Changes in VRQOL between Students and Working Graduates

The mean change in VRQOL for each subscale was similar between participants who were still pursuing full time studies and graduates who had started working. Despite the change in environment and daily routine, working graduates did not appear to exhibit a change in VRQOL compared to current students. This implies that the environment and activities do not affect VRQOL in this cohort of young adults, while the main factors are the amount of refractive error and the usage of contact lenses.

5.2.5. The NEI-RQL-42 Instrument

Although the NEI-RQL-42 is a widely-used instrument to measure VRQOL in relation to refractive error, problems exists inherently in this instrument. The responses of the questions are of a Likert scale where the difference between each consecutive response is wrongly assumed to be equal (McAlinden et al., 2011). Some questions had up to 6 responses, where not all responses have the equal chance to be chosen. Another issue is multidimensionality, where some questions do not solely address the subscale trait that it is assigned to. Targeting is also an issue, where the question is not able to accurately obtain a person’s response due to its difficult. The NEI-RQL-42 instrument had however fared positively, when subjected to analysis of internal consistency and reliability in two studies (Nichols et al., 2003; Pakpour et al., 2013). Despite the limitations of the NEI-RQL-42 instrument highlighted with Rasch analysis, it is still a valid and reliable instrument that can provide valuable insights on the satisfaction and dissatisfaction of their vision. The instrument was able to demonstrate significant differences in VRQOL scores between participants of different refractive groups, as well as using different modes of refractive correction. This valuable information would nonetheless be able to influence overall clinical decisions, in order to improve the outcomes and promote innovations in refractive corrections.

5.2.6. Summary

The findings from the present study indicate that patients with myopia suffer from poorer VRQOL, where higher myopia is associated with worse VRQOL. Participants who primarily used refractive correction such as spectacles and contact lenses had poorer VRQOL than those who did not. Multiple regression analysis revealed that higher magnitudes of negative refractive error were the primary cause of poorer VRQOL which resulted in the inevitable use of refractive correction. The present study also found that contact lens wear negatively impacted VRQOL, where participants had poorer visual quality and expected more out of their visual experience. The level of VRQOL remained stable for all participants, where there were no differences between the baseline and the 24 month visit for all subscales and the overall VRQOL global score. However, in higher myopes, there exists a possibility where they may become less dependent on their correction. This was likely due to adaptation from their current refractive correction, or possibly due to the availability of new modes of refractive correction (e.g. contact lenses). It was of interest to note that when students graduate from the polytechnic and enter the workforce, there was also no change in their VRQOL scores across all subscales. As such, this study has found VRQOL to be a stable parameter that can be easily measured to understand the overall well-being of a patient from a visual perspective. Further studies would be necessary to examine the effectiveness of interventions such as contact lenses or laser refractive surgery over time.

Chapter 6: General Conclusion

The programme of research presented in this thesis was the first to examine ocular biometric parameters in addition to refraction in Singapore young adults. The prevalence of myopia in this study was high, at 86.9 %, with the majority of participants (93.8 %) reporting an early onset of below 16 years of age. It can be established that the onset age of myopia is associated with higher magnitudes of myopia. As such, it is crucial for optometrists to be at the forefront of managing myopia progression with orthokeratology (Kakita et al., 2011), dual-focus contact lenses (Anstice and Phillips, 2011; Aller et al., 2016), and bifocal and multifocal spectacles (Cheng et al., 2010; Sankaridurg et al., 2010) in order to prevent the increasing prevalence of pathological myopia that is associated with high myopias (Wong et al., 2014; Verkicharla et al., 2015). The amount of near work, sports, and outdoor activities were not associated with the current magnitude of myopia. Even if these factors were associated with the progression of myopia earlier in their lives, the lifestyle of the participants might have changed over time. Similarly, the accommodative responses were not related to the magnitude of myopia at this stage of life, where the myopia has stabilised. Parental myopia remains a useful indicator for the risk of myopia, while future studies need to investigate the usefulness of the PSLE score as a surrogate for the amount of academic pressures in Singapore children during their primary school education.

This sample of young adults studying in a tertiary institution, which is of a slightly younger age group compared to university students, has not previously been examined for their ocular biometric parameters and VRQOL. The AL/CR ratio is a useful parameter that is strongly correlated to the magnitude of myopia, which has previously been to be used to screen the risk of developing myopia (Grosvenor and Scott, 1994; He et al., 2015). The author recommends the use of AL/CR ratio by clinicians to compare ocular dimensions between patients for the purpose of monitoring axial elongation. Over the course of 24 months, the ocular biometric parameters, refractive errors, and percentage of myopes remained stable, where there was no overall increase in myopia. There was also no difference in mean change of myopia between Mod/High-Myopes, Low-Myopes, and Non-Myopes.

The absence of myopia progression in this cohort of young adults provides valuable information for clinicians to be better informed that myopic changes would typically not occur in young adults studying in a polytechnic, as the academic pressures are not expected to be excessive. The small (state magnitude in D) hyperopic shift observed at the 12 month visit was likely due to the effect of over-accommodation at the baseline visit, that was better controlled at subsequent visits. Care should be taken when performing subjective refraction, where appropriate fogging and binocular balancing techniques have to be performed to reduce the likelihood of excessive accommodation. Since cycloplegic refractions were not performed due to the existing laws that prohibit the use of diagnostic pharmaceutical agents by optometrists in Singapore, it is important for future studies to use cycloplegic agents where possible to prevent the variability of accommodation, and to allow the accurate investigation of lens thickness changes over time.

Non-Myopes had the highest VRQOL scores, while Mod/High-Myopes exhibited significantly lower VRQOL scores. Whilst wearing spectacles appeared to lower VRQOL, contact lens wear did not improve VRQOL significantly. Higher magnitude of myopia was the main determinant of poorer VRQOL scores, followed by the usage of contact lenses. Contact lens usage was the sole factor contributing to poorer clarity of vision. The negative contributory factor of contact lens usage in this study suggests that contact lens wear was not readily assimilated by this group of young adults, who perhaps, do not crave spectacles-independence as much as those who are of an older age group or those who have become dependent on the usage of contact lenses. When prescribing contact lenses, it is recommended that clinicians be mindful of the potential desiccation and deposition issues, and provide the most accurate correction for the best possible visual outcome in order to maintain or even improve the patient's VRQOL.

VRQOL did not change over the 24 month period, suggesting that VRQOL largely remains stable and does not improve or worsen with the continual use of refractive correction. In addition, there is a possibility of adaptation for those with higher myopia, which may result in improvements of their Dependence on Correction subscale scores. With this understanding, clinicians can be assured that the VRQOL of patients does not significantly change over time. However, the potential improvement in VRQOL from interventions such as contact lenses and refractive surgery requires further investigations. Future studies can also confirm the phenomenon of adaptation improvement of VRQOL scores, especially in higher myopes.

In conclusion, the present study presents novel information in Singapore young adults on: (1) the high prevalence of myopia at 86.9 %; (2) the stability of myopia and ocular biometric parameters over a period of two years; (3) the stability of VRQOL over a period of two years; (4) myopia being the main contributory factor of poorer VRQOL; and (5) contact lens use being a secondary contributory factor of poorer VRQOL.

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Appendix 1: Ethics Approval

Published on *Aston University Ethics Committee* (http://www.ethics.aston.ac.uk)

Home > PhD Student Ethics Application 423

PhD Student Ethics Application 423

Submitted by Heng Kuen Kwan on Sat, 2012-10-06 04:42

Section A		
A1	Title Of Research (max 20 words):	**A longitudinal study of ocular biometry in Singapore young adults with high educational demands and their vision-related quality of life**
A2	Proposed Study Dates: Start Date	**1 December 2012**
A3	Proposed Study Dates: Finish Date	**30 September 2016**
A4	*Project Supervisor details:*	
A4a	Project Supervisor details: Title and Name	**Dr Amy Sheppard**
A4b	Project Supervisor details: Email Address	**A.Sheppard@aston.ac.uk**
A4c	Project Supervisor details: Telephone	**+44 (0)121 204 4208**
A5	School	
A6	*Student details:*	
A6a	Student details: Name	**Kwan, Heng Kuen Martin**
A6b	Student details: Email Address	**kwanhm@aston.ac.uk**

Section B		
Link to uploaded University Risk Assessment Form in PDF format:		
B - Upload	**No file uploaded**	
B1	Does the project involve participants selected because of their links with the NHS/clinical practice or because of their professional roles within the NHS/clinical practice, or does the research take place within the NHS/clinical practice, or involve the use of video footage	**No**

Section B		
	or other materials concerning patients involved in any kind of clinical practice ?	
B2	Does the project involve any i) clinical procedures or ii) physical intervention or iii) penetration of the participant's body or iv) prescription of compounds additional to normal diet or other dietary manipulation/supplementation or v) collection of bodily secretions or vi) involve human tissue which comes within the Human Tissue Act? (eg surgical operations; taking body samples including blood and DNA; exposure to ionizing or other radiation; exposure to sound light or radio waves; psychophysiological procedures such as fMRI, MEG, TMS, EEG, ECG, exercise and stress procedures; administration of any chemical substances)?	**No**
B3	Having reflected upon the ethical implications of the project and/or its potential findings, do you believe that the research could be a matter of public controversy or have a negative impact on the reputation/standing of Aston University?	**No**
B4	Does the project involve interaction with or the observation of human beings (either directly or remotely eg via CCTV or internet interactions) , including interactions, observations, surveys, questionnaires, interviews, blogs, etc ?	**Yes/Not Sure**

Section C		
C1	Will individual or group interviews/questionnaires discuss any topics or issues that might be sensitive, embarrassing or upsetting, or is it possible that criminal or other disclosures requiring action could take place during the study (eg during interviews/group discussions, or use of screening tests for drugs)	**No**
C2	*Does the project involve the deliberate selecton of participants from vulnerable groups:*	
C2a	Children (ie people under the age of 18)?	**Yes/Not Sure**
C2b	People with learning difficulties?	**No**
C2c	People with mental disabilities	**No**
C2d	Prisoners/detained persons	**No**
C2e	Aston students or staff	**No**
C2f	People with physical disabilities	**No/Not Relevant**
C2g	People over 65 years of age	**No/Not Relevant**

Section C		
C2h	Pregnant women	**No/Not Relevant**
C2i	Other vulnerable group	**No/Not Relevant**
	If Yes to C2i, please specify:	
C3	Does the research involve the deliberate deception of the participant?	**No**
C4a	Does the research involve the observation and/or recording (eg video, audio, CCTV, etc) of people?	**No**
	If you have answered "Yes/Not Sure" to answer C4a, Please answer Question C4b, otherwise please go to Question C5	
C4b	Will any people being observed and/or recorded not be informed that the observation and/or recording is taking place?	**No**
C5	Does the research involve the collection of confidential data and/or is there a risk that any participant could be identified from the data collected?	**No**

Section D		
D1	Research Protocol: provide a summary of the purpose, design and methodology of the planned research, including a brief explanation of the theoretical framework that informs it. A clear statement should be included of what will happen to participants (including, where appropriate, frequency, duration and in what order). No more than 1000 words.	
	The purpose of this longitudinal study is to report the changes in ocular biometry over 2 years in young adults studying in a tertiary institution, in relation to the risk factors of myopic axial elongation. In addition, the vision-related quality of life (VR-QOL) in different refractive groups will be reported. **The prevalence of myopia is reported to be the highest in East Asia, representing economic burdens due to the refractive correction and the medical treatment of its pathological complications. The prevalence and severity of myopia has been reported to be strongly associated with higher education; military conscripts with tertiary education were found to have a significantly higher prevalence of myopia compared to conscripts with no formal education (Tay et al. 1992, Wu et al. 2001). Despite these reports, there is a paucity of information on ocular biometry and refraction in young adults studying in polytechnics in Singapore of ages between 17 to 19 years,**	

Section D

as enlistees were conscripted into the military after polytechnic or pre-university education. Moreover, military conscripts are all males.

There have not been longitudinal studies to investigate ocular biometric changes in young adults between 17 to 19 years old in a polytechnic in Singapore. A three year study in Norway reported myopic progression of -0.52D with vitreous chamber elongation in university students (Kinge et al. 1999). Another study followed Turkey medical students for a year, reporting adult-onset myopia of 14.7% where parental myopia was an independent risk factor while outdoor activities were protective of myopia (Onal et al. 2007). Jorge et al. (Jorge et al. 2007) reported increased prevalence of myopia and hyperopia of 5.1% and 9.4% respectively in Portuguese university students. A five year study on Chinese medical students also found small but significant increase in myopia and axial length (Lin et al. 1996). While studies from these countries have reported myopic progression in university undergraduates, this information from polytechnic students in Singapore is unknown.

The survey of the quality of life has become an important aspect of clinical subjective assessment of ocular pathologies that can drastically affect visual acuity. Although uncorrected refractive error has been demonstrated to reduce the visual functioning related quality of life (Congdon et al. 2008, Lamoureux et al. 2009), there are inadequate reports to associate corrected myopia to VRQOL (Lamoureux and Wong 2010). Rose et al. reported decreased VRQOL in patients with high myopia and keratoconus using the vision core measure 1 (VCM1) questionnaire. Another study that employed the VisQoL instrument reported reduced VRQOL with spectacles and contact lens wear as compared to emmetropes and post-refractive surgery patients (Chen et al. 2007). There has yet to be an investigation into the VRQOL of young adults in Singapore with respect to refractive correction. As such, this study will report on the VRQOL of participants in different refractive groups.

Thus, this study will investigate the ocular biometry and refraction changes in polytechnic students over three years, with respect to the risk factors for myopic progression. The VRQOL will also be reported and compared between participants who do not need refractive correction, participants with low myopia and participants with high myopia. At least 100 participants will be recruited from the student pool of Ngee Ann Polytechnic. Students who present at the Ngee Ann Polytechnic Optometry Centre (NPOC) for an eye examination will also be recruited. Only healthy participants with no ocular diseases other than refractive errors will be recruited.

Section D

Participants will be asked for informed consent before data collection.

Upon obtaining informed consent, an eye examination will be performed for the participants if they did not have an optometric examination for the past year. A questionnaire will be given to the participant to obtain the information on age of myopia onset, history of myopia treatment, parental myopia, amount of outdoor activities, grades in school and the amount of near work in a week. The NEI-RQL-42 questionnaire will also be undertaken by the participant to obtain VRQOL data. Subjective manifest refraction will be performed, where the best corrected visual acuity will be obtained in LogMAR notation. On satisfying the inclusion and exclusion criteria, ocular biometry measurements of only the right eye will be performed using Optical Low-Coherence Reflectometry (OLCR) (Haag Streit Lenstar LS900). The OLCR allows highly repeatable measurements of the anterior chamber depth, lens thickness, choroidal thickness, vitreous chamber depth and the axial length (Buckhurst et al. 2009). Keratometry measurements of the right eye will also be obtained from the Lenstar LS900. Binocular distance autorefraction will be performed using the Grand Seiko WAM-5500 Binocular Autorefractor/Keratometer. The accommodative function will be analysed by performing autorefraction with the best spectacle correction at 0D, 1D, 2D, 3D, and 4D accommodative responses. Auto-refraction and laser ocular biometry measurements do not carry any known physical risks, are non-contact in nature and are performed using commercially available equipment. The duration for the baseline visit is about 45 minutes.

The participant will be requested to return for follow-up visits on the 12th and 24th month. During the follow-up visits, manifest subjective refraction, ocular biometry, binocular distance autorefraction and accommodation function will be performed on the right eye. A simplified questionnaire will be given to the participant to obtain information on grades, outdoor and near work activities for the past 12 months. The duration for each follow-up visit is about 30 minutes.

After the end of data collection, the ocular biometry and refraction distribution in the baseline visit, first year visit and second year visit will be quantified. Variables such as keratometry, anterior chamber depth, lens thickness, vitreous chamber depth and axial length will be compared between the baseline visit and the follow-up visits. Multivariate logistic regression analysis will be performed to determine whether risk factors such as parental myopia, outdoor activities, near work, accommodative function, age of myopia onset, and grades in school are statistically significant for the distribution, as well as the progression of myopia. The VRQOL will also be

Section D		
	analysed and compared between participants who do not need refractive correction, participants with low myopia and participants with high myopia.	
Link to Supporting Papers in PDF format:		
D1 - Upload	**No file uploaded**	
D2	Location of research: (enter details of all sites where research will take place and specifiy the elements of research to be undertaken at each centre)	
	The location where this research will take place is at the Ngee Ann Polytechnic Optometry Centre, 535 Clementi Road, Singapore 599489. All elements of the research will take place within Ngee Ann Polytechnic Optometry Centre.	
	Procedures:	
D3a	Substances to be administered (a substance is anything other than normal food - chemical constituents of food stuffs, ethanol and variation of the diet should be included here) and method of delivery should be specified:	
	Not applicable	
D3b	If drugs are to be used, do any require clinical trials certificate or clinical trials exemption certificate?	**No**
If Yes, please provide a copy of the certificate (.PDF format):		
D3b - Upload	**No file uploaded**	
D3c	Psychological assessment:	
	Not applicable	
D3d	Questionnaires: (only to be completed when project contains questionnaire(s) which fall within the types of questionnaire requiring Ethics Committee approval [see Guidelines D (3) in the ethics committee guidelines]). Indicate if the questionnaire has not yet been developed.	
	A questionnaire will be given to the participant to obtain the information on age of myopia onset, history of myopia treatment, parental myopia, amount of outdoor activities, grades in school and the amount of near work in a week. The Refractive Error Quality of Life instrument -42 will also be undertaken by the participant to obtain VRQOL data.	
Please attach ONE copy of the questionnaire:		
D3d - Upload	nei-rql-42.pdf	

Section D		
	questionnaire.docx	
D3e	D3e - Observation and/or Recording of People:	
	Not applicable	
D3f	Identify any procedures designed to be challenging physically or psychologically (including any physical exercise):	
	Not applicable	
D3g	Identify any new equipment to be tested:	
	Not applicable	
D3h	If this work involves human tissue does it come within the Human Tissue Act (HTA)? (If yes please consult with the Designated Individual for the HTA, currently c.j.bailey (c.j.bailey@aston.ac.uk)).	**No**
	Participants: (complete the following sections where appropriate)	
D4a	Number of Participants:	
	At least 100	
D4b	Over what time span will participants be used?	
	2 years	
D4c	Criteria for selection of participants:	
	Inclusion Criteria **• Males and Females** **• Any race or religion** **• 17 years to 19 years of age at baseline examination** **• Able to understand and undertake the informed consent process** **Exclusion Criteria** **• Any systemic health problems that may result in ocular complications** **• Any ocular diseases other than refractive errors** **• History of ocular surgery including laser procedures** **• Any type of ocular or systemic medications that can potentially alter refraction**	
D4d	Source of participants:	
	Students of Ngee Ann Polytechnic	
D4e	Will payments be made to the participants?	**No**

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	If Yes, how much will each be paid?	
D4f	Are the participants patients ?	**No**
	If Yes state diagnosis and clinic/responsible practitioner:	
D4g	Does the study have any specific exclusion criteria for participants ?	**Yes**
	D4g - If Yes, on what grounds?	
	Patients who have any ocular diseases, history of laser or surgical procedures or certain medications may affect refractive error measurements.	
D	*If Not Sure, explain why not:*	
D4h	Is the activity of the participant to be restricted in any way either before or after the procedure? (eg diet, driving)	**No**
	If Yes, Please specify duration and type(s) of restriction:	
Please attach a .PDF file containing consent form(s) and information provided to participants and to parents/guardians etc detailing how procedures and hazards are explained:		
D4i - Upload	**No file uploaded**	
D4j	Will all participants in the research be in a position to give informed consent ?	**Yes**
	If No: please explain why it is not possible to gain the participant's consent and the justification for undertaking the research without it:	
D4k	What measures have been made for participants who might be vulnerable or might not adequately understand verbal explanations or written information given in English or have special communication needs (eg translation, use of interpreters, use of chaperones, presence of guardians, researchers from same gender as participants etc)?	
	Not applicable as only participants who are able to understand and undertake the informed consent process will be recruited.	
D4l	What measures have been made to ensure that any participants who are believed to be under some form of duress (eg staff, students, prisoners,	

Section D		
	members of the armed forces, employees of companies sponsoring research) are not coerced into participating	
	Ensuring that the participants understand that participation is completely voluntary. Informed consent is to be taken before performing any procedures on the participants, and that the participants are aware of the time taken and the discomfort that will be experienced during the procedures. The participants must also be made aware that they can withdraw from the research study at any point of time.	
D4m	What arrangements have been made to provide indemnity and/or compensation in the event of a claim by, or on behalf of, participants for negligent and/or for non-negligent harm? Please note that you should not undertake to provide any form of indemnity or insurance cover without first referring the matter to the Deputy Director of Finance for her/his consideration.	
	Covered by Aston's policy	
Attach one PDF file containing copies of insurance certificate(s) if available:		
D4m - Upload	**No file uploaded**	
D4n	Will participants be informed that they may withdraw from the study at any time ?	**Yes**
	Risks and Ethical issues:	
D5a	What do you consider to be the main ethical issues which may arise from the proposed research and give full details of any hazards, pain, discomfort, distress, inconvenience or use of deception which could affect the health, safety or well-being of any participant, or any other person who might be affected by the research. (There is no need to repeat information provided in D4 above).	
	Participants may experience mild discomfort due to dryness when asked to keep their eyes open for a period of time during the measurements. Participants may be inconvenienced by these additional tests that may not be necessary apart from the requirements of this study. Although the privacy and confidentiality of research participants cannot be guaranteed, it will be protected vigorously to the extent permissible by law as stated in section D7a.	
D5b	What levels of risk are associated with these hazards?	
	The level of risks is very low, as the tests performed are by commercially available ophthalmic equipment which are non-contact in nature.	
D5c	How do you propose to control the risks associated with these hazards?	

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	The following additional protections of the research participants in place. They are: (1) Ensuring informed consent is taken before performing any procedures on the participants. (2) Ensuring that the participants are aware of the time taken and the discomfort that will be experienced during the procedures. (3) Ensuring that the participants are aware that they can withdraw from the research study at any point of time.	
D5d	What criteria have you used to determine whether the risks are acceptable?	
	The risk assessment form has been used to determine that the risk is minimal.	
D5e	Is there any precedent for this research ? If so, please give details with references if possible.	
	Yes, on other population and age group. **Kinge et al. conducted a three year study to investigate the ocular biometric changes of university students in Norway (Kinge et al. 1999). Another study by Onal et al. followed medical students for a year reported 14.7% of adult-onset myopia (Onal et al. 2007). Jorge et al. reported that 22% of participants had myopic progression of at least 0.50D (Jorge et al. 2007). A 5 year longitudinal study by Lin et al. also found small, but significant increase in myopia and axial length in medical students (Lin et al. 1996). Apart from the study by Lin et al., the above longitudinal studies were investigating non-East Asian participants.** **Rose et al. (Rose et a. 2000) reported decreased VRQOL in patients with high myopia and keratoconus using the vision core measure 1 (VCM1) questionnaire. Another study that employed the VisQoL instrument reported reduced VRQOL with spectacles and contact lens wear as compared to emmetropes and post-refractive surgery patients (Chen et al. 2007).**	
D5f	Has this project been considered/is it being considered by any other Ethical Committee? If so, please give details and decision made. (If the project involves participants selected because of their links with the NHS, or because of their professional roles within the NHS, or the research take place within the NHS it must be must be submitted to the appropriate NHS Local Research Ethics Committee (LREC) or Multicentre REC (MREC))	
	No	
Please attach one PDF file containing copies of any approval letter(s) from other Ethics Committees		

Section D		
D5f - Upload	**No file uploaded**	
	Dissemination of Findings:	
D6a	How will the results be made available to participants and communities from which they are drawn?	
	At the conclusion of the study, the results will be emailed to the research participants.	
	Confidentiality and Data Protection:	
D7a	What measures have been put in place to ensure security and confidentiality of personal data and any video/audio recordings ?	
	All case record forms will not contain participant's names. Participants will be identified by a unique participant number. A database that identifies each participant's number will be created and stored in a computer that is locked by password. The database itself will also be encrypted by a different password. Only the investigator has the passwords to assess the computer and the database. At the end of this research study, the database that identifies the patient will be deleted from the computer. Although the privacy and confidentiality of research participants cannot be guaranteed, it will be protected vigorously to the extent permissible by law.	
D7b	Where and by whom will the data be analysed?	
	Ngee Ann Polytechnic, by student investigator: Kwan, Heng Kuen Martin	
D7c	Who will have access to the data generated by the study?	
	Student investigator: Kwan, Heng Kuen Martin **Supervisor: Dr Amy Sheppard**	
D7d	When will personal data and any video/audio recordings be destroyed following completion of the research ?	
	The records of this research study will be marked to be retained in Ngee Ann Polytechnic for at least 5 years after the last examination. After 5 years, the records will be sent for incineration.	
	Peer Review:	
D8a	Has the quality of the research been assessed?	**No**
	If yes, then indicate how the research has been assessed (please upload copies of any referees' comments or other scientific critique reports):	

Section D		
Please attach one PDF file containing copies of any comments received:		
D8a - Upload	**No file uploaded**	
D9a	Please Specify Name of Sponsoring Organisation (if applicable):	
	No Sponsoring Organisation Specified	
D10a	Is insurance cover provided by the sponsor ?:	**No**
D11a	*Contact Details of Other Investigators:*	
	No Investigators Specified	

Links to uploaded PDF files		
D3d - Upload	**nei-rql-42.pdf** **questionnaire.docx**	

STATEMENT BY NAMED INVESTIGATORS, HEAD OF SCHOOL AND (if necessary) RESEARCH SUPERVISOR:

I consider that the details given constitute a true summary of the project and that the hazards and potential risks to any participant are accurately described. I undertake to abide by the ethical principles underlying the Declaration of Helsinki and good practice guidelines on the proper conduct of research. The Principal Investigator is the main point of contact for the University Ethics Committee, and accordingly should be a member of academic staff of the University (this implies that supervisors of research students will be the Principal Investigator and main point of contact).

	Signature	**Date**
Principal Investigator Or Supervisor of Student		
Head of School (or Nominee)		

Reviewers Comments	
Reviewer 1 Comments:	
Date of Review 1:	
Reviewer 1 Files:	
Reviewer 2 Comments:	
Date of Review 2:	
Reviewer 2 Files:	
Reviewer 3 Comments:	
Date of Review 3:	
Reviewer 3 Files:	
Resubmitted Applications	
Resubmission Form:	
Other Documents:	
Applicant Comments:	
Reviewer 1 Comments:	
Reviewer 1 Files:	
Reviewer 2 Comments:	
Reviewer 2 Files:	
Reviewer 3 Comments:	
Reviewer 3 Files:	
Committee Comments:	
Committee Comments	
Committee Comments:	
Date of Approval:	

Source URL: http://www.ethics.aston.ac.uk/content/phd-student-ethics-application-423

Aston University
Birmingham

Aston Triangle
Birmingham B4 7ET
United Kingdom
Tel +44 (0)121 204 3000

www.aston.ac.uk

Memo

Life and Health Sciences Research Ethics Committee's Decision Letter

To: Dr Amy Sheppard

Cc: Rachel Giles, administrator to the Life and Health Sciences Research Ethics Committee

From: Dr Robert Morse

Chair of the Life and Health Sciences Research Ethics Committee

Date: 22/1/2013

Subject: Project : #423 A longitudinal study of ocular biometry in Singapore young adults with high educational demands and their vision-related quality of life

---

I am sorry for the delay in approving your study. We needed to consult the University Ethics Committee (UEC) because your study involved data collection abroad. UEC have allowed us to review your proposal but suggest that you should check with Alan Hawkesworth for the insurance liability. I do not foresee any difficulty and I am therefore happy for this study to proceed.

Reviewer's recommendation: Approved.

Reviewer's comments: This study may now proceed.

Please see the tabled list below of approved documents:

Documentation	Version/s	Approved
Consent Form	1.0	√
Participant Information Sheet (PIS)	1.0	√
Protocol	1.0	√
Risk Assessment	1.0	√
Questionnaires	NEI-RQL-42 Version 1 Bespoke questionnaire version 1.0	√
Other (please detail)		

After starting your research please notify the LHS Research Ethics Committee of any of the following:

> **Substantial amendments.** Any amendment should be sent as a Word document, with the amendment highlighted. The amendment request must be accompanied by all amended documents, e.g. protocols, participant information sheets, consent forms etc. Please include a version number and amended date to the file name of any amended documentation (e.g. "Ethics Application #100 Protocol v2 amended 17/02/12.doc").
>
> **New Investigators**
>
> **The end of the study**

Please email all notifications and reports to lhs_ethics@aston.ac.uk and quote the original project reference number with all correspondence.

Ethics documents can be downloaded from: http://www.ethics.aston.ac.uk/documents-all. Please note that these documents can ONLY be opened using Mozilla Firefox or the latest Internet Explorer version (IE9).

Statement of Compliance

The Committee is constituted in accordance with the Government Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

Yours sincerely

Dr Robert Morse
Chair of the LHS Research Ethics Committee

Application Form - A longitudinal study of ocular biometry in...

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Manage | Actions

E: Synopsis of Project | F: Collection of Materials | G: Informed Consent | H: Cost | I: Safety

J: PI's Declaration | Endorsement & Approval

(View/Print) All Fields | A: Project Title/Team | B: Project Funding | C: Classification of Project | D: Participant Info

NGEE ANN POLYTECHNIC INSTITUTIONAL REVIEW BOARD (NP-IRB) Application Form

Project Title	A longitudinal study of ocular biometry in Singapore young adults with high educational demands and their vision-related quality of life
Is this a Consultancy Project?	
Date of commencement of project	1/3/2013
Date of completion of project	30/9/2016

Date of Research requiring IRB Approval

From	
To	

SECTION A: PROJECT TEAM

1. Principal Investigator

A: 1a	Name:	Kwan Heng Kuen
A: 1b	School/Centre:	HS
A: 1c	Contact (DID/Mobile):	64606645 / 97597918
A: 1d	Email:	khk2@np.edu.sg

2. Co-Investigator/Student #1

A: 2.1a	Name:	
A: 2.1b	School/Centre:	
A: 2.1c	Contact (DID/Mobile):	
A: 2.1d	Email:	

Application Form - A longitudinal study of ocular biometry in...

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2. Co-Investigator/Student #2	
A: 2.2a	Name:
A: 2.2b	School/Centre:
A: 2.2c	Contact (DID/Mobile):
A: 2.2d	Email:
2. Co-Investigator/Student #3	
A: 2.3a	Name:
A: 2.3b	School/Centre:
A: 2.3c	Contact (DID/Mobile):
A: 2.3d	Email:
3. Collaborator #1	
A: 3.1a	Name:
A: 3.1b	School/Centre:
A: 3.1c	Contact (DID/Mobile):
A: 3.1d	Email:
3. Collaborator #2	
A: 3.2a	Name:
A: 3.2b	School/Centre:
A: 3.2c	Contact (DID/Mobile):
A: 3.2d	Email:
3. Collaborator #3	
A: 3.3a	Name:
A: 3.3b	School/Centre:
A: 3.3c	Contact (DID/Mobile):
A: 3.3d	Email:

Application Form - A longitudinal study of ocular biometry in...

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SECTION B: PROJECT FUNDING

B: Q1	Source of grant/fund:	
B: Q2a	Total amount of grant/fund:	
B: Q2b	Status of grant:	Not applicable

SECTION C: CLASSIFICATION OF PROJECT

C: Q1	Nature of Project:	Clinical Research
C: Q2a	Human participants (Target Number):	100
C: Q2b	Project May Involve:	Healthy Volunteers; Children (under 21 years old)
C: Q3a	Project participants will be:	Not Reimbursed
C: Q4a	Has this research been reviewed by any IRB/REC/DSRB?	No
C: Q5a	Has this research been rejected by any IRB/REC/DSRB?	

SECTION D: PROJECT PARTICIPANT INFORMATION

To be submitted by PI:
* A copy of the advertising material and soliciting script.
* A copy of the data collection sheet/survey form.

D: Q1	What is the mode of recruitment of participants?	Participants will be recruited from the student pool of Ngee Ann Polytechnic by means of advertisement via email, social media, or by word of mouth. The advertisement will also be pinned up at the optometry centre.
D: Q2	What personal identifiers will be collected?	Participant's name, gender, month and year of birth, age, ethnicity, year of study, and course of study will be collected.
D: Q3a	Do participants have a dependent relationship with the Project team?	Yes
D: Q3b	If answer to Q3a is 'Yes', please describe dependent relationship:	Lecturer-student

Application Form - A longitudinal study of ocular biometry in...

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SECTION E: SYNOPSIS OF PROJECT

E: Q1

Provide an abstract of your proposed project, including aim (purpose) and hypothesis.	The purpose of this longitudinal study is to report the changes in ocular biometry over 2 years in young adults studying in a tertiary institution, in relation to the risk factors of myopic axial elongation. In addition, the vision-related quality of life (VR-QOL) in different refractive groups will be reported. There have not been longitudinal studies to investigate ocular biometric changes in young adults between 17 to 19 years old in a polytechnic in Singapore, while studies from other countries have reported myopic progression in university undergraduates. There has also yet to be an investigation into the VRQOL of young adults in Singapore with respect to refractive correction. Thus, this study will investigate the ocular biometry and refraction changes in polytechnic students over three years, with respect to the risk factors for myopic progression. The VRQOL will also be reported and compared between participants who do not need refractive correction, participants with low myopia and participants with high myopia. The hypotheses are that there will be a statistically significant • change in ocular biometry and refraction in polytechnic students over two years. • relationship between the proportion of baseline myopia and the associated risk factors • relationship between myopia progression and the associated risk factors • difference in VRQOL between participants who do not require refractive correction, low myopic participants and high myopic participants

E: Q2

State the methodology in carrying out this project (the method of administering any sampling, including route of administration or collection, dose, dose interval and period for investigation, list of ingredients or compounds, devices or gadgets and alternatives used and/or software applications).	Participants will be students of Ngee Ann Polytechnic and will be recruited by convenience sampling. Upon obtaining informed consent, an eye exam will be performed for the participants if they did not have an optometric examination for the past year. A questionnaire will be undertaken by the participant to obtain the age of myopia onset, history of myopia treatment, parental myopia, amount of outdoor activities, grades in school and amount of near work in a week. The NEI-RQL-42 questionnaire will be undertaken by the participant to obtain VRQOL data. Subjective refraction will be performed, where the best corrected visual acuity will be obtained in LogMAR notation. On satisfying the inclusion and exclusion criteria, ocular biometry of only the right eye will be measured. Keratometry measurements of the right eye will also be obtained. Binocular distance autorefraction will be performed using the Grand Seiko WAM-5500 Binocular Autorefractor, where accommodative responses will be analysed by performing autorefraction with the best spectacle correction at 0D, 1D, 2D, 3D, and 4D. The duration for the baseline visit is about 45 minutes. The participant will be requested to return for follow-up visits on the 12th and 24th month, where subjective refraction, ocular biometry, autorefraction and accommodation function will be performed on the right eye. A simplified questionnaire will be given to the participant to obtain information on grades, outdoor and near work activities for the past 12 months. The duration for each follow-up visit is about 30 minutes.

Application Form - A longitudinal study of ocular biometry in...

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E: Q3	What are the potential benefits of the project to the participants or others?	This project will provide valuable data towards understanding the ocular biometric measurements and refractive error distribution and changes in polytechnic students. Also, this project will provide information regarding the quality of life of polytechnic students with high and low myopia. However, the participants will not benefit directly from this study. As such, the results from this study may benefit future patients.
E: Q4	What are the known or foreseen risks to the participants associated with the procedures in carrying out the project, and the procedures/ precautions taken to minimise the potential risks?	Participants may experience mild discomfort due to dryness when asked to keep their eyes open for a period of time during the measurements. Participants may be inconvenienced by these additional tests that may not be necessary apart from the requirements of this study. These additional procedures are performed with commercially available equipment designed for eye tests on humans, and do not subject the participants to risks or harm. Additional protections of the research participants in place are: (1) Ensuring informed consent is taken before performing any procedures on the participants. (2) Ensuring that the participants are aware of the time taken and the discomfort that will be experienced during the during the procedures. (3) Ensuring that the participants are aware that they can withdraw from the research study at any point of time.

SECTION F: COLLECTION OF BIOLOGICAL MATERIALS

F: Q1a	Will any biological materials be collected (e.g. blood or tissue) as part of this project?	No
F: Q2	The biological materials are obtained:	
F: Q3	State how the biological materials are collected (e.g. Tissue Repository, equipment used, technique used):	
F: Q4	Indicate the quantity of biological, materials required for this project:	
F: Q5	What tests will be performed using the biological materials?	
F: Q6	Will the biological materials be destroyed at the completion of the study or will they be stored for future use?	

Application Form - A longitudinal study of ocular biometry in...

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SECTION G: INFORMED CONSENT

Note to PI:
The PI is rsponsible for ensuring that all participants give informed consent before enrolling into the project.

G: Q1	Who will obtain informed consent from participants? (list name of staff)	Kwan Heng Kuen, Martin
G: Q2	Will the participant be asked to give consent to allow subsequent usage of the collected data for further or another research after the completion of this project?	Yes
G: Q3	Will the participant sign any informed consent prior to the initiation of any procedure?	Yes
G: Q4a	Are you requesting for a waiver of the informed consent form?	No

SECTION H: COST OF PARTICIPATION

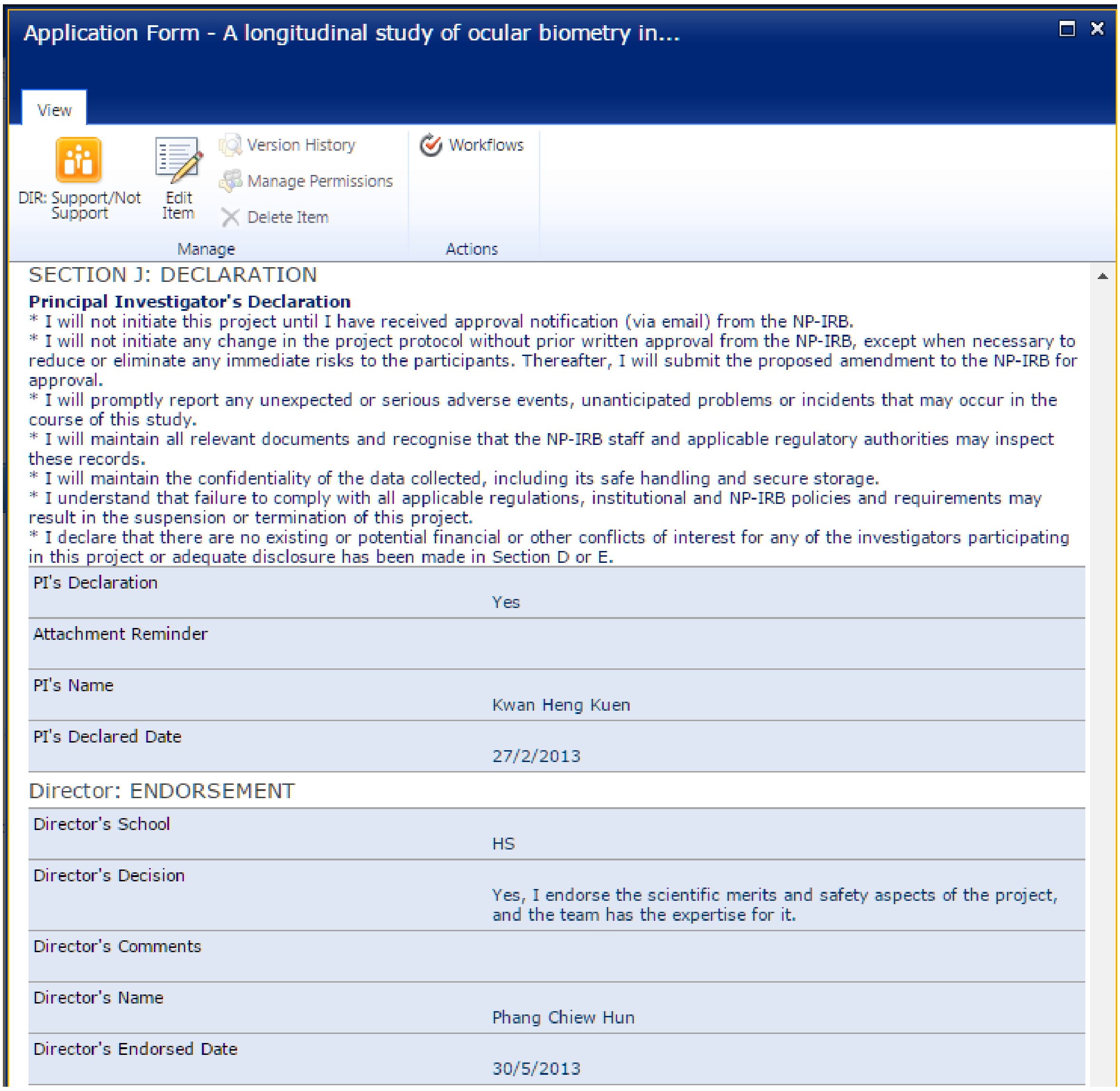
Note to PI:
* The NP-IRB recommends that each participant be paid at the end of each visit.
* The suggested amount is $10 per hour and $40 for a two-way transport.

H: Q1	Time cost per visit per participant (please state the duration required for each visit):	45 minutes
H: Q2	Transport cost per visit per project participant:	No reimbursement will be paid

SECTION I: SAFETY MONITORING

Note to PI:
* The PI to conduct Risk Assessment before commencement of the project.
* The PI is responsible for reporting any adverse events or reactions expected or unexpected to the NP-IRB no later than 7 days after the event.

I: Q1	Who will conduct the safety monitoring? (List name and tel. no. of staff)	Kwan Heng Kuen, Martin (DID 64606645)
I: Q2	What are the criteria for stopping the project?	Any serious adverse events or unexpected adverse reactions that seriously threatens the safety of participants



Application Form - A longitudinal study of ocular biometry in...

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SECTION J: DECLARATION

Principal Investigator's Declaration

* I will not initiate this project until I have received approval notification (via email) from the NP-IRB.
* I will not initiate any change in the project protocol without prior written approval from the NP-IRB, except when necessary to reduce or eliminate any immediate risks to the participants. Thereafter, I will submit the proposed amendment to the NP-IRB for approval.
* I will promptly report any unexpected or serious adverse events, unanticipated problems or incidents that may occur in the course of this study.
* I will maintain all relevant documents and recognise that the NP-IRB staff and applicable regulatory authorities may inspect these records.
* I will maintain the confidentiality of the data collected, including its safe handling and secure storage.
* I understand that failure to comply with all applicable regulations, institutional and NP-IRB policies and requirements may result in the suspension or termination of this project.
* I declare that there are no existing or potential financial or other conflicts of interest for any of the investigators participating in this project or adequate disclosure has been made in Section D or E.

PI's Declaration	Yes
Attachment Reminder	
PI's Name	Kwan Heng Kuen
PI's Declared Date	27/2/2013

Director: ENDORSEMENT

Director's School	HS
Director's Decision	Yes, I endorse the scientific merits and safety aspects of the project, and the team has the expertise for it.
Director's Comments	
Director's Name	Phang Chiew Hun
Director's Endorsed Date	30/5/2013

Application Form - A longitudinal study of ocular biometry in...

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Director's Name	Phang Chiew Hun
Director's Endorsed Date	30/5/2013

Secretariat/Panel: APPROVAL

There are 3 categories:

* **Full Board Review** - PI > Director > Secretariat > System Administrator > IRB Panel
* **Expedited** - PI > Director > Secretariat > System Administrator
* **Exempted** - PI > Director > Secretariat > System Administrator

Category	Expedited

Secretariat:

Reviewer's Decision	Yes, this project is granted expedited approval
Reviewer's Comments	
Reviewer's Name	Lau Quek Choon
Reviewed Date	10/6/2013

Panel: (Full Board Review)

Panel's Decision	
Panel's Comments	
Panel's Name	
Panel's Reviewed Date	

Approved Project

Project Code	NPIRB-P0002-2013-HS-KHK2
Status of Application	Expedited Approval
Date of Application Status	10/6/2013
PI's reply to IRB enquiries	

Created at 27/2/2013 4:01 PM by Kwan Heng Kuen
Last modified at 23/7/2013 4:45 PM by Wong Lye Yoong
Dynamic Forms for SharePoint v2.65

Close

Appendix 2: Patient Information Sheet

Patient Information Sheet and Consent Form

Research workers, school and subject area responsible

Dr Amy Sheppard, Optometry, School of Life & Health Sciences, Aston University
Dr Nicola Logan, Optometry, School of Life & Health Sciences, Aston University
Mr Kwan Heng Kuen, Martin. School of Health Sciences, Ngee Ann Polytechnic,
535 Clementi Road, Singapore 599489

Project Title

A longitudinal study of ocular biometry in Singapore young adults with high educational demands and their vision-related quality of life

Invitation

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?

The purpose of this research study is to find out the changes to the various measurements of the eyeball over a span of two years. The proportion of students with perfect eyesight, near-sightedness and far-sightedness as well as the risk factors that may contribute to short-sightedness will be investigated. In addition, the quality of life of participants who use spectacles and contact lens correction will be analysed and compared to participants who do not use any correction. Having the above knowledge will allow the understanding of how the eye changes in young adults of age between 17 to 19 years and its relationship with various risk factors, as well as their differences in vision-related quality of life.

Why have I been chosen?

You have been chosen because you are considered to be a suitable candidate, as this study will perform the investigations on healthy participants. Individuals that do not have any eye diseases, health conditions that may affect the eye are invited to participate.

What will happen to me if I take part?

If you volunteer to participate in this research study, you will be invited to visit the eye clinic at Ngee Ann Polytechnic every 12 months for a period of 2 years, for around 40 minutes, to sit for a series of non-invasive, non-contact tests.

An eye health examination will be conducted if you have not had an eye examination within two years. Your eye power will be examined by using subjective methods (asking if which lenses are better) as well as objective methods to determine eye focus (using a machine). The Lenstar instrument will measure your corneal curvature, central corneal thickness, anterior chamber depth (distance between your cornea and crystalline lens), crystalline lens thickness and axial length (distance between your cornea and retina). All instruments use lights to take measurements and are commercially available for testing of human eyes. You will also be asked to complete 2 simple questionnaires; one relating to your history of spectacle/ contact lens use (if applicable), and another on vision-related quality of life.

Are there any potential risks in talking part in the study?

There are no known risks involved with the instruments or techniques listed above. All measurements will be taken by a qualified, registered optometrist.

Do I have to take part?

No, you do not have to participate if you do not wish to do so. You are free to withdraw at any time from the project. Your decision to participate (or not) will not influence your ability to participate in any future research, or to receive care from the Ngee Ann polytechnic clinic.

Expenses and payments:

There are no expenses or payments for the participation of this research study.

Will my taking part in this study be kept confidential?

Yes. Your particulars and your participation in this study will be kept confidential. All case record forms will not contain participant's names. Participants will be identified by a unique participant number. A database that identifies each participant's number and the computer that holds this information will be locked by different passwords. Only project investigators have the passwords to access the computer and the database. Although the privacy and confidentiality of research participants cannot be guaranteed, it will be protected vigorously.

What will happen to the results of the research study?

The results of this research study will be of academic use. The results may also be published in scientific journals. The results will not identify individual participants. You can obtain a copy of the results by contacting Mr Martin Kwan (khk2@np.edu.sg , Office : 6460 6645 Mobile : 9759 7918)

Who is organising and funding the research?

This research is an individual project with Aston University, carried out at Ngee Ann Polytechnic. There is no funding for this research.

Who has reviewed the study?

The research has been submitted and granted approval by the Research Ethics Committee of the School of Life and Health Sciences, Aston University, UK.

Who do I Contact if Something Goes Wrong or I need Further Information?

Please contact Mr Kwan Heng Kuen, Martin (khk2@np.edu.sg , Office : 6460 6645 Mobile : 97597918) or the principal investigator, Dr Amy Sheppard a.sheppard@aston.ac.uk

Who do I contact if I wish to make a complaint about the way in which the research is conducted

If you have any concerns about the way in which the study has been conducted, then you should contact the Secretary of the University Research Ethics Committee at j.g.walter@aston.ac.uk or telephone +44(0)121 204 4665.

Appendix 3: Consent Form

Personal Identification Number for this study: ☐ ☐ ☐

CONSENT FORM

Title of Project
A longitudinal study of ocular biometry in Singapore young adults with high educational demands and their vision-related quality of life

Research Venue
Ngee Ann Polytechnic Optometry Centre

Names of Investigators
Dr Amy Sheppard
Dr Nicola Logan
Mr Kwan Heng Kuen, Martin

		Please initial in box
1.	I confirm that I have read and understand the information sheet for the above study (dated November 2012, V1.0). I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
2.	I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected.	☐
3.	I agree to take part in the above study.	☐

______________________	__________	______________
Name of participant	Date	Signature
______________________	__________	______________
Name of person taking consent	Date	Signature

1 copy for research participant
1 copy for investigator

Appendix 4: Bespoke Questionnaire

A LONGITUDINAL STUDY OF OCULAR BIOMETRY IN SINGAPORE YOUNG ADULTS WITH HIGH EDUCATIONAL DEMANDS AND THEIR VISION-RELATED QUALITY OF LIFE		
BASELINE VISIT Questionnaire	**Date of Visit** (DD/MM/YYYY) ☐☐/☐☐/☐☐☐☐	**Participant Number** ☐☐☐

Guidelines

- Please answer every question.
- In circumstances when a question does not apply to you, you will be directed to skip that question.
- Please try to give your best response for questions that may present to be difficult.
- If you are not sure about the answers of some questions at the point of completing the questionnaire, the investigator may request to follow-up with an email to obtain the answers on another day.
- Please feel free to ask the investigators for any assistance by contacting with the email address and the telephone number below.

Mr Martin Kwan
Investigator
School of Health Sciences
Ngee Ann Polytechnic
Telephone: 6460 6645
Email: khk2@np.edu.sg

Dr Amy Sheppard
Principal Investigator
School of Life and Health Sciences
Aston University
Telephone: +44 (0)121 204 4208
Email: A.sheppard@aston.ac.uk

Confidentiality

- Information that would permit the identification of any person completing this questionnaire will be regarded as strictly confidential.
- All information provided will not be used for any other purpose other than the data analysis of this research, and will not be disclosed or released for any other purpose without your consent.

Q1 What is your gender?

☐ Male [1]
☐ Female [0]

Q2 What is your month and year of birth?

M M / Y Y Y Y

Q3 What is your ethnic group? (You may tick more than one option if you have a mixed-ethnicity)

☐ Chinese [1]
☐ Malay [2]
☐ Indian [3]
☐ Eurasian [4]
☐ Others [5], please specify : ________________

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Q4 Which year of study are you in?

- ☐ 1st year [1]
- ☐ 2nd year [2]
- ☐ 3rd year [3]
- ☐ 4th year [4]
- ☐ 5th year [5]

Q5 What is the diploma programme that you are enrolled in?

____

Q6 Do you have or use spectacles or contact lenses to correct your eyesight?

- ☐ Yes [1]
- ☐ No [0] **(skip to Q8)**

Q7 At what age did you start requiring for vision correction for your eyesight such as spectacles

☐☐ years old

Q8 Please state the percentage of time when you wear spectacles, contact lenses, and with no vision correction when you are not sleeping. The total of should be 100%.

	☐☐☐ %	Spectacles
+	☐☐☐ %	Contact Lens
+	☐☐☐ %	No vision correction / Zero power cosmetic spectacle or contact lenses
=	100 %	Total of non-sleeping hours

Q9 On average, how many hours do you spend doing the following activities?

For duration lesser than an hour, refer to the chart below to obtain decimal equivalent for recording

Minutes	50	40	30	20	10
Hours	0.83	0.67	0.50	0.33	0.17

	On a weekday	On a weekend day
Reading notes, books, literature and other printed material for schoolwork	☐☐.☐☐ hours	☐☐.☐☐ hours
Reading books, magazines, articles, journals and other printed materials for pleasure or recreation	☐☐.☐☐ hours	☐☐.☐☐ hours
Viewing, playing or reading smart phones, tablets and other portable electronic gadgets for any purpose	☐☐.☐☐ hours	☐☐.☐☐ hours
Using desktop computers, laptop computers and monitor screens for any purpose	☐☐.☐☐ hours	☐☐.☐☐ hours
Watching television, DVDs, Blu-rays, videos	☐☐.☐☐ hours	☐☐.☐☐ hours
Playing video games on the television (xbox, playstation 3, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours
Doing out of doors leisure activities (walking, gardening, picnic, fishing, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours
Doing or playing outdoor sports (running, cycling, soccer, swimming, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours
Doing or playing indoor sports (treadmill, weights training, indoor badminton, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours

Q10 Have you ever had one or more of the following treatments for short-sightedness control?

- ☐ Atropine eye drops [1]
- ☐ Bifocal spectacles [2]
- ☐ Orthokeratology (Corneal reshaping therapy) [3]
- ☐ Progressive spectacles [4]
- ☐ None [0]
- ☐ Not sure [5]

Q11 Do you know if your biological mother has any of these eye sight conditions? (you may tick more than one option)

- ☐ Short-sightedness (myopia) [1]
- ☐ Far-sightedness (hyperopia) [2]
- ☐ Near vision reading reading problems (presbyopia) [3]
- ☐ None of the above conditions [0] **(skip to Q14)**
- ☐ Not sure [4]

Q12 Do you know if your biological mother uses any of the following vision correction options? (you may tick more than one option)

- ☐ Spectacles most of the time [1]
- ☐ Spectacles some of the time or when required [2]
- ☐ Contact lens most of the time [3]
- ☐ Contact lens some of the time or when required [4]
- ☐ Not sure [1]

Q13 Do you know if your biological mother requires spectacles or contact lenses for the following situations?

- ☐ Seeing clearly in the distance only [1]
- ☐ Seeing clearly when reading or doing near work only [2]
- ☐ Seeing clearly for both distance vision and reading or doing near work [3]
- ☐ Not sure [4]

Q14 Do you know if your biological father has any of these eye sight conditions? (you may tick more than one option)

- ☐ Short-sightedness (myopia) [1]
- ☐ Far-sightedness (hyperopia) [2]
- ☐ Near vision reading reading problems (presbyopia) [3]
- ☐ None of the above conditions [0] **(skip to Q17)**
- ☐ Not sure [4]

Q15 Do you know if your biological father uses any of the following vision correction options? (you may tick more than one option)

- ☐ Spectacles most of the time [1]
- ☐ Spectacles some of the time or when required [2]
- ☐ Contact lens most of the time [3]
- ☐ Contact lens some of the time or when required [4]
- ☐ Not sure [5]

Q16 Do you know if your biological father requires spectacles or contact lenses for the following situations?

- ☐ Seeing clearly in the distance only [1]
- ☐ Seeing clearly when reading or doing near work only [2]
- ☐ Seeing clearly for both distance vision and reading or doing near work [3]
- ☐ Not sure [4]

Q17 What was your Primary School Leaving Examinations (PSLE) score?

- ☐ Below 179 [1]
- ☐ 180 to 199 [2]
- ☐ 200 to 219 [3]
- ☐ 220 to 239 [4]
- ☐ 240 to 259 [5]
- ☐ 260 to 279 [6]
- ☐ 280 or higher [7]

Q18 What was your L1R2B2 GCE 'O' Levels aggregate prior to CCA deduction?

- ☐ 5 or below [1]
- ☐ 6 to 10 [2]
- ☐ 11 to 15 [3]
- ☐ 16 to 20 [4]
- ☐ 21 to 25 [5]
- ☐ 26 or higher [6]

Q19 What was your L1R2B2 GCE 'O' Levels aggregate after the deduction of CCA grade?

- ☐ 5 or below [1]
- ☐ 6 to 10 [2]
- ☐ 11 to 15 [3]
- ☐ 16 to 20 [4]
- ☐ 21 to 25 [5]
- ☐ 26 or higher [6]

Q20 Have you completed your first semester at NP and received the results?

- ☐ Yes [1]
- ☐ No [0] **(skip Questions 21 and 22)**

Q21 What was your Grade Point Average (GPA) for the most recent semester?

- ☐ 3.50 and above [1]
- ☐ 3.00 to 3.49 [2]
- ☐ 2.50 to 3.00 [3]
- ☐ 2.00 to 2.49 [4]
- ☐ 1.50 to 1.99 [5]
- ☐ Below 1.50 [6]

Q22 What is your cumulative Grade Point Average (GPA) at NP so far?

- ☐ 3.50 and above [1]
- ☐ 3.00 to 3.49 [2]
- ☐ 2.50 to 3.00 [3]
- ☐ 2.00 to 2.49 [4]
- ☐ 1.50 to 1.99 [5]
- ☐ Below 1.50 [6]

End of Questionnaire

A LONGITUDINAL STUDY OF OCULAR BIOMETRY IN SINGAPORE YOUNG ADULTS WITH HIGH EDUCATIONAL DEMANDS AND THEIR VISION-RELATED QUALITY OF LIFE		
12 MONTH VISIT Questionnaire	**Date of Visit** (DD/MM/YYYY) ☐☐/☐☐/☐☐☐☐	**Participant Number** ☐☐☐

Guidelines

- Please answer every question.
- In circumstances when a question does not apply to you, you will be directed to skip that question.
- Please try to give your best response for questions that may present to be difficult.
- If you are not sure about the answers of some questions at the point of completing the questionnaire, the investigator may request to follow-up with an email to obtain the answers on another day.
- Please feel free to ask the investigators for any assistance by contacting with the email address and the telephone number below.

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Confidentiality

- Information that would permit the identification of any person completing this questionnaire will be regarded as strictly confidential.
- All information provided will not be used for any other purpose other than the data analysis of this research, and will not be disclosed or released for any other purpose without your consent.

Q1 Which one of the following statuses applies to you?

☐ Student at Ngee Ann Polytechnic [1]
☐ Graduated from Ngee Ann Polytechnic [2]
☐ Others [3], please specify : __________________

Q2 Tick the checkboxes that best describes what you are doing now? (Skip this question if you are still a student at NP)

☐ Working full-time (typically ≥40 hours a week) [1]
☐ Working part-time (typically <40 hours a week) [2]
☐ Studying full-time [3]
☐ Studying part-time [4]
☐ Others [5], please specify : __________________

Q3 Which year of study are you in? (Skip this question if you are no longer a student in NP)

☐ 1st year [1]
☐ 2nd year [2]
☐ 3rd year [3]
☐ 4th year [4]
☐ 5th year [5]

Q4 How would you describe your visual demands now (i.e. time and effort spent reading / doing computer work / using vision for very important tasks) as compared to one year ago?

☐ The demand for my vision has increased [1]
☐ The demand for my vision has decreased [2]
☐ The demand for my vision has not changed [3]

Q5 Please state the percentage of time when you wear spectacles, contact lenses, and with no vision correction when you are not sleeping. The total should be 100%.

	☐☐☐ %	Spectacles
+	☐☐☐ %	Contact Lens
+	☐☐☐ %	No vision correction / Zero power cosmetic spectacle or contact lenses
=	100 %	Total of non-sleeping hours

Q6 What was your Grade Point Average (GPA) for the most recent semester? (Skip this question if you are no longer a student at NP)

☐ 3.50 and above [1]
☐ 3.00 to 3.49 [2]
☐ 2.50 to 3.00 [3]
☐ 2.00 to 2.49 [4]
☐ 1.50 to 1.99 [5]
☐ Below 1.50 [6]

Q7 What is / was your cumulative Grade Point Average (GPA)?

☐ 3.50 and above [1]
☐ 3.00 to 3.49 [2]
☐ 2.50 to 3.00 [3]
☐ 2.00 to 2.49 [4]
☐ 1.50 to 1.99 [5]
☐ Below 1.50 [6]

For Q8 and Q9, consider if the following conditions applies to your parents.

Short-sightedness or myopia

- Unable to see clearly at distance without spectacles or contact lenses.
- Able to read up close without spectacles or contact lenses.
- Spectacle lenses are of a minus (-) power for distance vision.
    - Spectacle lenses that are of a minus (-) power are thicker at the edges.
    - When holding the spectacles further from the eye, images will appear smaller through the lenses.
- Contact lenses are of a minus (-) power.

Far-sightedness or hyperopia

- Require spectacles of a positive (+) power for distance vision.
    - Spectacle lenses that are of a positive (+) power are thicker at the centre.
    - When holding the spectacles further from the eye, images will appear bigger through the lenses.
- Contact lenses are of a positive (+) power.

Q8 Do you know if your biological mother has any of these eye sight conditions? (you may tick more than one option)

☐ Short-sightedness or myopia [1]
☐ Far-sightedness or hyperopia [2]
☐ None of the above conditions [0]
☐ Not sure [4]

Q9 Do you know if your biological father has any of these eye sight conditions? (you may tick more than one option)

- ☐ Short-sightedness or myopia [1]
- ☐ Far-sightedness or hyperopia [2]
- ☐ None of the above conditions [0]
- ☐ Not sure [4]

Q10 For the past year, how many hours on average do you spend doing the following activities during school term / work?

For duration lesser than an hour, refer to the chart below to obtain decimal equivalent for recording

Minutes	50	40	30	20	10
Hours	0.83	0.67	0.50	0.33	0.17

	On a weekday	On a weekend day
Reading notes, books, literature and other printed material for schoolwork	☐☐.☐☐ hours	☐☐.☐☐ hours
Reading books, magazines, articles, journals and other printed materials for pleasure or recreation	☐☐.☐☐ hours	☐☐.☐☐ hours
Viewing, playing or reading smart phones, tablets and other portable electronic gadgets for any purpose	☐☐.☐☐ hours	☐☐.☐☐ hours
Using desktop computers, laptop computers and monitor screens for any purpose	☐☐.☐☐ hours	☐☐.☐☐ hours
Watching television, DVDs, Blu-rays, videos	☐☐.☐☐ hours	☐☐.☐☐ hours
Playing video games on the television (xbox, playstation 3, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours
Doing out of doors leisure activities (walking, gardening, picnic, fishing, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours
Doing or playing outdoor sports (running, cycling, soccer, swimming, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours
Doing or playing indoor sports (treadmill, weights training, indoor badminton, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours

End of Questionnaire

A LONGITUDINAL STUDY OF OCULAR BIOMETRY IN SINGAPORE YOUNG ADULTS WITH HIGH EDUCATIONAL DEMANDS AND THEIR VISION-RELATED QUALITY OF LIFE		
24 MONTH VISIT **Questionnaire**	**Date of Visit** (DD/MM/YYYY) ☐☐/☐☐/☐☐☐☐	**Participant Number** ☐☐☐

Guidelines

- Please answer every question.
- In circumstances when a question does not apply to you, you will be directed to skip that question.
- Please try to give your best response for questions that may present to be difficult.
- If you are not sure about the answers of some questions at the point of completing the questionnaire, the investigator may request to follow-up with an email to obtain the answers on another day.
- Please feel free to ask the investigators for any assistance by contacting with the email address and the telephone number below.

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Dr Amy Sheppard
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Confidentiality

- Information that would permit the identification of any person completing this questionnaire will be regarded as strictly confidential.
- All information provided will not be used for any other purpose other than the data analysis of this research, and will not be disclosed or released for any other purpose without your consent.

Q1 Which one of the following statuses applies to you?

- ☐ Student at Ngee Ann Polytechnic [1]
- ☐ Graduated from Ngee Ann Polytechnic [2]
- ☐ Others [3], please specify : ___________________

Q2 Tick the checkboxes that best describes what you are doing now? (Skip this question if you are still a student at NP)

- ☐ Working full-time (typically ≥40 hours a week) [1]
- ☐ Working part-time (typically <40 hours a week) [2]
- ☐ Studying full-time [3]
- ☐ Studying part-time [4]
- ☐ Others [5], please specify : ___________________

Q3 Which year of study are you in? (Skip this question if you are no longer a student in NP)

- ☐ 1st year [1]
- ☐ 2nd year [2]
- ☐ 3rd year [3]
- ☐ 4th year [4]
- ☐ 5th year [5]

Q4 How would you describe your visual demands now (i.e. time and effort spent reading / doing computer work / using vision for very important tasks) as compared to one year ago?

- ☐ The demand for my vision has increased [1]
- ☐ The demand for my vision has decreased [2]
- ☐ The demand for my vision has not changed [3]

Q5 Please state the percentage of time when you wear spectacles, contact lenses, and with no vision correction when you are not sleeping. The total should be 100%.

	☐☐☐ %	Spectacles
+	☐☐☐ %	Contact Lens
+	☐☐☐ %	No vision correction / Zero power cosmetic spectacle or contact lenses
=	100 %	Total of non-sleeping hours

Q6 What was your Grade Point Average (GPA) for the most recent semester? (Skip this question if you are no longer a student at NP)

- ☐ 3.50 and above [1]
- ☐ 3.00 to 3.49 [2]
- ☐ 2.50 to 3.00 [3]
- ☐ 2.00 to 2.49 [4]
- ☐ 1.50 to 1.99 [5]
- ☐ Below 1.50 [6]

Q7 What is / was your cumulative Grade Point Average (GPA)?

- ☐ 3.50 and above [1]
- ☐ 3.00 to 3.49 [2]
- ☐ 2.50 to 3.00 [3]
- ☐ 2.00 to 2.49 [4]
- ☐ 1.50 to 1.99 [5]
- ☐ Below 1.50 [6]

For Q8 and Q9, consider if the following conditions applies to your parents.

Short-sightedness or myopia

- Unable to see clearly at distance without spectacles or contact lenses.
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Far-sightedness or hyperopia

- Require spectacles of a positive (+) power for distance vision.
  - Spectacle lenses that are of a positive (+) power are thicker at the centre.
  - When holding the spectacles further from the eye, images will appear bigger through the lenses.
- Contact lenses are of a positive (+) power.

Q8 Do you know if your biological mother has any of these eye sight conditions? (you may tick more than one option)

- ☐ Short-sightedness or myopia [1]
- ☐ Far-sightedness or hyperopia [2]
- ☐ None of the above conditions [0]
- ☐ Not sure [4]

Q9 Do you know if your biological father has any of these eye sight conditions? (you may tick more than one option)

- ☐ Short-sightedness or myopia [1]
- ☐ Far-sightedness or hyperopia [2]
- ☐ None of the above conditions [0]
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Viewing, playing or reading smart phones, tablets and other portable electronic gadgets for any purpose	☐☐.☐☐ hours	☐☐.☐☐ hours
Using desktop computers, laptop computers and monitor screens for any purpose	☐☐.☐☐ hours	☐☐.☐☐ hours
Watching television, DVDs, Blu-rays, videos	☐☐.☐☐ hours	☐☐.☐☐ hours
Playing video games on the television (xbox, playstation 3, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours
Doing out of doors leisure activities (walking, gardening, picnic, fishing, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours
Doing or playing outdoor sports (running, cycling, soccer, swimming, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours
Doing or playing indoor sports (treadmill, weights training, indoor badminton, etc)	☐☐.☐☐ hours	☐☐.☐☐ hours

End of Questionnaire

Aston University

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