Efficacy of Multifocal Soft Contact Lens on Asthenopic Orthophoric and Esophoric Myopes with Lag of Accommodation

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Thesis Summary

The primary aim of this study was to investigate the effectiveness of multifocal soft contact lenses (MFSCLs) in alleviating asthenopic symptoms in symptomatic, orthophoric and esophoric myopes with lag of accommodation by using clinical methods that are commonly used in general practice. Also, whether the amount of MFSCL addition differentially modifies symptoms of asthenopic individuals was assessed.

This study found that Convergence Insufficiency Symptom Survey (CISS) score improved after wearing MFSCLs, when comparing to spectacle (SPECT) and single vision contact lenses (SVCLs). There was no significant difference between the symptom score of multifocal low add (LAMFCLs) and high add contact lenses (HAMFCLs), implying that varying the amount of near addition did not improve the symptom score. Accommodative lag was not significantly improved with MFSCLs. Distant esophoric shift was observed when changing from SPECT to SVCLs and HAMFCLs. Near esophoric shift was found to be lower for both MFSCLs when compared to SVCLs.

Accommodation response changes with MFSCLs wear after a period of one month were also studied. Amplitude of accommodation (AoA) and near point of convergence (NPC) was improved while wearing MFSCLs. Increased positive relative accommodation (PRA) and decreased negative relative accommodation (NRA) was observed while wearing HAMFCLs. No adaptation effect was observed after one month of wearing MFSCLs.

One hundred Singapore optometrists were surveyed, and it was found that 75% were seeing asthenopic patients, with the most common symptoms being tired eyes. Ophthalmic lenses were the most commonly prescribed treatment and had a high success rate. The majority (69%) of the surveyed optometrists have not considered the use of MFSCLs as a treatment option.

In conclusion, this study presented novel findings showing that MFSCLs are effective in relieving asthenopic symptoms. The study finding also suggested that pre-presbyopic individuals do not use the near addition power provided by MFSCLs to replace their accommodative activity, and that MFSCLs do not create a significant change in the phoric status at near. Further work is required to determine whether the improvement in asthenopic symptoms with MFSCLs is contributed by negative SA.

Key words: Asthenopia, Multifocal, Myopes, Orthophoric, Esophoric, Accommodation, Contact lenses, Spherical aberration

For Kim Kuan and Boon San

My Beloved Mum and Dad

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List of Abbreviations

AoA	Amplitude of Accommodation
AC/A	Accommodation Convergence and Accommodation
ANOVA	Analysis of Variance
AS-OCT	Anterior Segment Optical Coherence Tomography
BLF	Blue Light Filter
BR	Bell Retinoscopy
CA/C	Convergence Accommodation/Accommodation
CL	Contact Lens
CISS	Convergence Insufficiency Symptoms Survey
CSF	Contrast Sensitivity Function
ESVL	Enhanced Single Vision Lens
HCVA	High-Contrast Visual Acuity
HAMFCL	High Add Multifocal Contact Lens
LAMFCL	Low Add Multifocal Contact Lens
LE	Left Eye
LCVA	Low-Contrast Visual Acuity
MEM	Monocular Estimate Method
MFSCL	Multifocal Soft Contact Lens
NFV	Negative Fusional Vergence
NITM	Near Work-Induced Transient Myopia
NPC	Near Point of Convergence
NR	Nott Retinoscopy
NRA	Negative Relative Accommodation
PAL	Progressive Addition Lens

PD	Pupil Distance
PRA	Positive Relative Accommodation
PFV	Positive Fusional Vergence
RAF	Royal Air Force
RE	Right Eye
SA	Spherical Aberration
SE	Spherical Equivalent
SVCL	Single Vision Contact Lens
SVN	Single Vision Near
SPECT	Spectacle
SPH	Spherical
TBI	Traumatic Brain Injury
VA	Visual Acuity
VB	Visual Breaks
VDT	Visual Display Terminal
VT	Visual Therapy

Unit of Measurements

cm	Centimetres
D	Diopters
m	Metres
mm	Millimetres
Δ	Prism Diopters
SD	Standard Deviation

1.0 Introduction

In developed countries, the advancement of the internet and mobile devices has greatly changed our lifestyle, be it for work or leisure. The use of digital electronic devices, such as the computers, smartphones and tablets to check e-mail, social media and entertainment are becoming very common. Based on Singapore digital marketing statistics (Digitalinfluencelabcom, 2015), it was found that Singapore has the highest internet penetration rate in South East Asia, with each Singaporean owning an average of three devices, with the smartphone being the most popular and most used device. In the survey, it was also reported that Singaporeans spend about four hours on a computer and about two hours on a smartphone each day. Another statistical survey conducted by TNS global (2015) on 60,000 internet users worldwide reported that those aged 16–33 years, spend an average of 3.2 hours a day on their mobile devices. The Straits Time newspaper article of 3rd April 2017, based on an Ernst & Young survey report on 'The Digital Habit of Singaporeans' (EY, n.d; Lin and Toh, 2017) found that Singaporeans' time spent on digital devices has increased to 12 hours 42 minutes a day.

Asthenopic visual symptoms have been reported in studies to arise from prolonged use of the eyes, particularly for near-range work (Grisham et al., 1993; Murata et al., 1996; Owens and Wolf-Kelly, 1987). Symptoms may become more common as the distance of near tasks decreases. Bababekova et al. (2011) reported that all subjects in their study had a mean working distance of 36.2 cm when reading text from their smartphone, with 75% of the subjects having viewing distances between 26 cm to 40 cm and 22.5% of the subjects having a viewing distance of less than 30 cm. The viewing distance was significantly reduced to an average of 32.2 cm when viewing a website. It indicated that viewing distance is much closer compared to the typical near working distance of 40 cm for most individuals when reading printed material, and this close viewing distance will greatly increase the visual demands on both the ocular vergence and accommodation, which may worsen the fatigue symptoms that already existed with the longer viewing distance.

The reduction was further confirmed by Long et al. (2017), who investigated the viewing distances and eyestrain symptoms in 18 young adults after reading from a smartphone for 60 minutes. The study found that viewing distances of smartphones decreased at the end of the 60 minutes from 30.6 cm with a standard deviation (SD) of 7.2 at the beginning to about 27.8 cm (SD 7.7). The viewing distance reported was much shorter than the average viewing distance that was observed by Bababekova et al. (2011). Long et al. (2017) also reported that the eyestrain symptom scores increase when the viewing distance becomes closer to the eye.

Besides the change in viewing distance and target size, most individuals' accommodative response to a near target may be less than the accommodative stimulus due to the presence of the depth-of-focus (i.e. accommodative lag) (Tassinari, 2002), resulting in not being able to focus accurately during near-range tasks. Multiple studies (Gwiazda et al., 1993; McBrien and Millodot, 1986; Tarrant et al., 2008) have reported that myopic individuals, while wearing their distance prescription, present with higher amounts of lag of accommodation compared to emmetropes during near-range work, and this amount of inaccuracy in focusing increases with reduced target distance. This higher amount of lag of accommodation seen in myopic individuals was speculated to be due to the reduced steady-state accommodative responses at near ranges and poorer blur sensitivity that was found in several studies (Ong and Ciuffreda, 1997; Rosenfield and Abraham-Cohen, 1999).

Even though asthenopia can be a condition of multiple causes (Sheedy et al., 2003), lag of accommodation may be one of the contributing factors to the symptoms of ocular fatigue. Brinbaum (2008) also reported that lag of accommodation was observed to significantly increase in the high discomfort group, and it was proposed that this might be an indication of an accommodative fatigue effect rather than an insufficiency in individuals with higher amounts of lag of accommodation. Chase et al. (2009) also reported a similar finding and found that there was a strong correlation between symptoms of asthenopia and accommodative lag, showing that when accommodative lag increases, symptoms of asthenopia also increase.

Contact lenses (CLs) have been one of the most commonly used visual corrective methods. However, care must be taken when switching from spectacles to CLs because they can cause lag of accommodation to increase, causing some CL wearers to experience more visual fatigue symptoms compared to spectacle wearers (Jiménez et al., 2011). The remedy for the fatigue symptoms is to reduce the amount of the accommodative error at near ranges. This reduction can be achieved by prescribing a lower myopic distance prescription for spectacles or CLs for the myopic individuals, or low plus lenses for the emmetropic individuals, mainly for near tasks (Brinbaum, 2008; Jiang et al., 2007; Madrid-Costa et al., 2011; Rosenfield and Carrel, 2001; Tosha et al., 2009). For some conditions, progressive addition lenses (PALs) or bifocal lenses can be prescribed to reduce visual fatigue symptoms in pre-presbyopes (Brinbaum, 2008). In recent years, enhanced single vision lenses (ESVLs) (e.g. anti-fatigue lenses by Essilor and Digital lenses by Zeiss) have been introduced to help pre-presbyopic individuals who suffer from visual fatigue (Essilor Visual Fatigue Solution, n.d; Zeiss Digital Lenses, n.d). These lenses incorporate a small amount of plus power in the inferior part of the lenses to help focus on near objects, thus producing lower accommodation error at near ranges and resolving the symptoms of visual fatigue.

Because prolonged lag of accommodation may cause visual fatigue (Tosha et al., 2009), and lowering the myopic prescription can reduce the lag of accommodation (Bao et al., 2013; Gwiazda et al., 2004; Koomson et al., 2015; Koomson et al., 2016; Nakatsuka et al., 2005) resulting in reduced symptoms of visual fatigue, multifocal soft contact lenses (MFSCLs) may be another option for symptomatic visual fatigue individuals. Therefore, in Chapter 3 of this thesis, the objective is to use common clinical methods to assess whether the use of MFSCLs can reduce asthenopic symptoms in symptomatic orthophoric and esophoric myopes with lag of accommodation.

The study will also assess whether the amount of MFSCL addition will differentially modify symptoms of asthenopia individuals.

Previous studies (Llorent-Guillemot et al., 2012; Madrid-Costa et al., 2013) have concluded that presbyopic participants fitted with simultaneous image MFSCLs perform well. Good visual acuity (VA) and visual performance is preserved, indicating that simultaneous image MFSCLs can help a person focus on near objects better when accommodation is attenuated with age. Multiple studies (Barodawala and Dave, 2014; Gong et al., 2017; Kang and Wildsoet, 2016; Lee et al., 2015; Libassi et al, 1985; Madrid-Costa et al., 2011; Pettersson et al., 2011; Tarrant et al., 2008) have been conducted to assess the accommodative response of pre-presbyopic subjects fitted with MFSCLs. Some of the studies have shown that accommodative response in pre-presbyopic individuals was affected by the near addition of the MFSCLs, while other studies indicated that pre-presbyopic adults do not react to the near addition power in the multifocal lenses. These studies use different lens design, addition power and different methods of accommodation test, which might explain the different derived conclusions. Most importantly, there was no adaptation period for the wearer wearing the MFSCLs in most of the studies (Gong et al., 2017; Madrid-Costa et al., 2011; Pettersson et al., 2011), with only two studies (Kang and Wildsoet, 2016; Lee et al., 2015) providing a two-week and one-week period of adaptation, respectively.

In Chapter 4 of this thesis, it is, therefore, interesting to know how the accommodation response of participants wearing MFSCLs will be after one month of wear and the resultant data collected will provide more information on the accommodative profile of a pre-presbyopic individual. Instead of using objective devices, clinical methods to measure the amplitude of accommodation (AoA) (push up/push down method), relative accommodation and lag of accommodation (Monocular Estimate Method retinoscopy) will be used. These tests are selected since they are the most common test methods most clinicians use in their practices and can provide a good testing method for real-life practice, should the test lenses show effectiveness in reducing the symptoms of asthenopia.

Besides understanding the effectiveness of MFSCLs on visual fatigue and the effect of the addition power on accommodation system, Chapter 5 of this thesis will conduct a survey with Singapore optometrists to better understand the frequency rate that optometrists were encountering visual fatigue complaints and what is/are the common management plan(s) used to solve the visual symptoms. Due to the fact that lowering the distance prescription or by prescribing a low plus power spectacle can be a common option for treatment of visual fatigue, and with the lack of literature reviewing the effectiveness of MFSCLs with asthenopia, this survey will also explore optometrists' views regarding the use of MFSCLs as a treatment option for visual fatigue patients. One hundred optometrists from private practices, hospitals, private clinics, schools of optometry and any sectors that require the work of optometrists will be randomly approached to participate in this survey.

2.0 Literature Review

2.1 Mechanism of Accommodation

Human eyes can change their refractive power of the lens and bring the object of interest to focus at various distances on the retina. Scheiner in 1619, first demonstrated this ability using a double pinhole experiment (Daxecker, 1992; Ovenseri–Ogabomo and Oduntan, 2015). The experiment was conducted monocularly while viewing through the double pinhole in a card and observing the object as single. However, when a second object was placed closer to the eyes than the first object, the second object appeared to be double and required the eye to change its refractive power to view the second object singly. This experiment concluded that the human eye is unable to view objects of far and near distances simultaneously and requires some form of change to the focusing of the eye to see objects clearly at various distances. This ability was originally termed ‘adaptation’ until Burow in 1841 (Michaels, 1985; Werner et al., 2000) introduced the word ‘accommodation’.

When reviewing the literature on the mechanism of accommodation, there were several explanations of how the mechanism works and there is still controversy to what is known about it. Cramer (1853) first described the mechanism by measuring the Purkinje image during accommodation and noted that the image reduced in size during accommodation. It was proposed that the vitreous compressed against the posterior crystalline lens when the ciliary muscle contracted and acted on the choroid, while the iris resisted the subsequent lens pressure, causing an increase in the anterior surface of the crystalline lens in the pupillary area. However, this theory was refuted by a study showing accommodation in an aniridia patient, which supports Young's theory that accommodation was responsible by the crystalline lens (Ovenseri–Ogabomo and Oduntan, 2015). Other explanations on the mechanism have been proposed and are listed below:

1. Helmholtz's relaxation theory of accommodation,
2. Tscherning's zonular contraction theory,
3. Coleman's theory of accommodation,
4. Schachar's theory of accommodation.

With various theories and evidence supporting each of them, the actual mechanism for accommodation remains inconclusive. However, Helmholtz' theory on accommodation perhaps is the most widely accepted (Ovenseri–Ogabomo and Oduntan, 2015).

Based on the Helmholtz (1854–1939) theory of accommodation (Helmholz, 1909; Ovenseri–Ogabomo and Oduntan, 2015), the contraction of the ciliary muscle moves the apex of the ciliary body towards the lens equator, resulting in tension release of the zonular at the lens equator, which causes the capsule moulding the lens to be more spherical and into an accommodative form. Sheppard et al. (2010) visualised the adult human ciliary muscle using Anterior Segment Optical Coherence Tomography (AS-OCT), and reported a shortening of the ciliary muscle length and thickening of the most anterior part of the ciliary muscle closest to the scleral spur. Their finding supported Helmholtz's theory whereby during accommodation most of the ciliary muscle shifted anteriorly and inward, resulting in zonular tension reduction. During accommodation, the diameter of the lens decreases, with the apex of the lens moving away from the sclera, with an increase in the curvature of the anterior and posterior lens surfaces causing the dioptric power of the lens to increase and therefore an increase in the dioptric power of the eye (see Figures 1 and 2) (Glasser and Kaufman, 1999; Helmholtz, 1909). The increase in power is called positive accommodation, and the reduction of power when the accommodation is relaxed is termed negative accommodation. Helmholtz's theory was later modified by Gullstrand (1909/1962; 1911) and Fincham (1937), followed by further modifications by Coleman (1970) and Fisher (1969), which eventually became what is most accepted today.

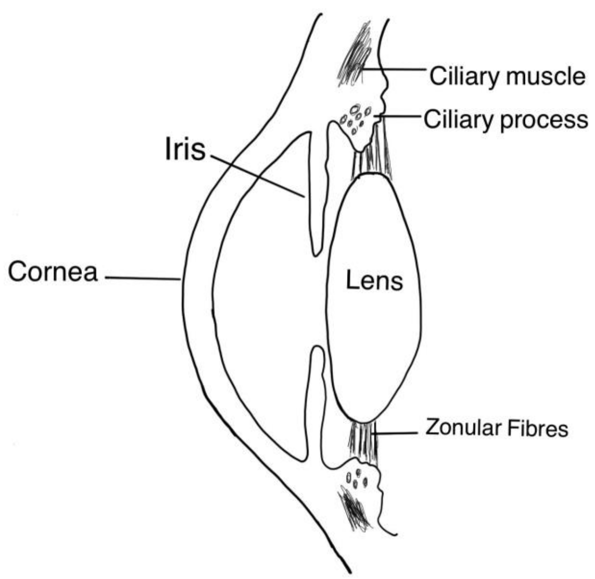


Figure 1: Ocular accommodative apparatus.

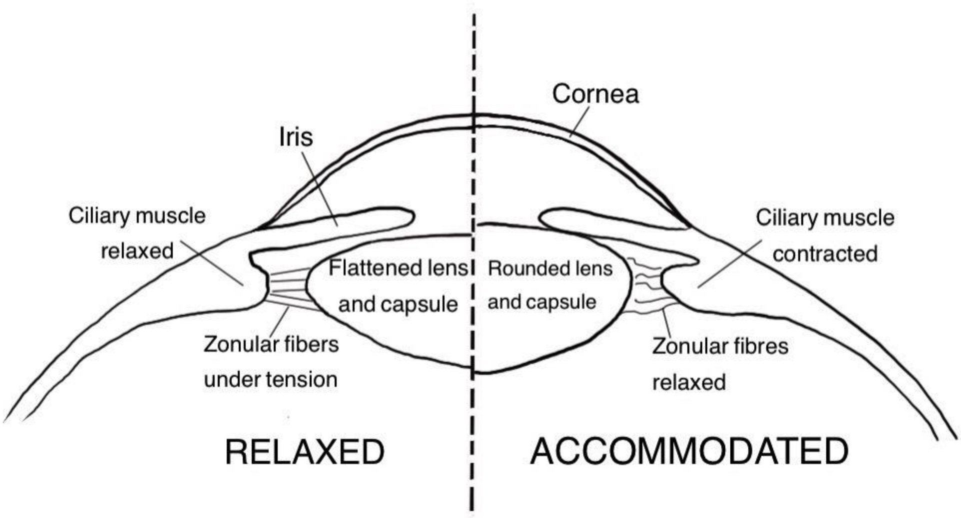


Figure 2: Change in the thickness and curvature of the lens during accommodation.

Accommodation is measured in diopters (D), which can be determined by the reciprocal of the fixation distance. For example: if the fixation distance is at 1 metre (m), it corresponds to 1 D of accommodation, and when the fixation distance is changed to 40 cm, it corresponds to 2.5 D of accommodation.

For the accommodation system to function, other components of accommodation are required to contribute to the accommodation response. These components were suggested by Heath (1956), whose idea was based on Maddox's classification for convergence. The components described by Heath (Charman, 2008; Heath, 1956) were:

1) Reflex accommodation – This is an automatic adjustment of the refractive state of the eyes to obtain clear and sharply focused images when blur input is detected. It was suggested by Fincham that the system can act over a range of 2 D to 2.5 D (Heath, 1956).

2) Proximal or psychic accommodation – This form of accommodation occurs due to the knowledge of nearness of an object and is more physiological in nature.

3) Convergence accommodation – This type of accommodation is driven by the innate neurological linking and fusion disparity vergence.

4) Tonic accommodation – This is accommodation that occurs in the absence of visual stimuli and can be found during dark focus or an empty field, such as in a low level of illumination or viewing a clear sky. This condition adopted a mean tonic accommodation of approximately 1 D, which represents the tonus innervation of the ciliary body at rest (Rosenfield et al., 1993).

Although all the components play an important role in determining the full accommodative responses under different environments and conditions, reflex accommodation is the most important. During the change of fixation from one point to another, reflex accommodation responds to the blur cue and changes the accommodative condition to keep the object of interest clear (Heath, 1956).

Besides dioptric power changing during accommodation, changes to the visual axes also occur. When focusing is changed to view a near object, there is an increase in the angle of the visual axes, which is known as convergence. When focusing is changed to a far object, a decrease in the angle of the visual axes results, known as divergence (Morgan, 1944). During fixation at near distances, pupillary constriction (miosis) occurs (Von Noorden, 1985);

therefore, accommodation, convergence and miosis work together as a synkinesis, forming what is known as the near triad (Benjamin, 1998; Emslie et al., 2007; Von Noorden and Campos, 2002).

In this thesis, the neural pathway that innervates the accommodation will not be discussed. Emphasis will be on the amplitude of accommodation, the lag of accommodation and relative accommodation.

2.1.1 Amplitude of Accommodation (AoA)

For a person to be able to focus clearly on an object up close, it depends on the accommodative ability of the eye, which is known as the amplitude of accommodation (AoA), or the accommodation response.

The AoA is defined as the ability of the focus response to the closest near object that can be produced using the maximal voluntary effort in the fully corrected eyes (Benjamin, 1998).

Measuring of the AoA is one of the recommended components during a routine clinical eye examination in the UK (Burns et al., 2014). By conducting a routine AoA examination, it can help to detect the common refractive condition, such as presbyopia and latent hyperopia, which can assist the practitioners to manage the conditions. The AoA measurement can also detect other pathological conditions that are due to systemic conditions, medication related, or even physiological causes (Burns et al., 2014).

Although the ability to accommodate and focus on things clearly at near ranges is always present, accommodation amplitude decreases with age and this has been shown from the data collected by Duane et al. (1912) (Figure 3). Based on Duane and Donder's work, Hofstetter (Hofstetter, 1950; Sterner et al., 2004) derived a set of formulae to calculate the range of the AoA of a certain age range. The formulas are as follows:

1. Minimum amplitude = 15 – (0.25 x age),
2. Expected amplitude = 18.5 – (0.3 x age),
3. Maximum amplitude = 25 – (0.4 x age).

These calculations allow the comparison of the AoA from the daily clinical findings of individuals in the expected range of Duane's data (Ovenseri–Ogbomo et al., 2012).

With age, there is a progressive loss of accommodative amplitude, and it will come to a point in life that the AoA is reduced to an amount whereby it is difficult to maintain sharp vision at the usual reading distance; this is known as Presbyopia (Werner et al., 2000).

2.1.2 Measuring the Amplitude of Accommodation (AoA)

There are five common clinical methods to measure the AoA clinically: push-up test, push-down test, push-down to recognition, minus-lens test and dynamic retinoscopy (Burns et al., 2014). Among these five methods, four of the tests are subjective and only dynamic retinoscopy is partially objective, as it still depends largely on the examiner to decide where the end point reflex is. Although a fully objective method to obtain the AoA can be achieved using the open-field autorefractor, this method is not commonly used compared to the five methods mentioned above, because the equipment is not widely available in optometric practice (Burns et al., 2014).

The subjective push-up test is the most ubiquitous clinical test used to measure the AoA because of its simple clinical technique (Burns et al., 2014; Duane, 1912; Wold et al, 2003). To conduct this test, a person must be fully corrected for their distance prescription and required to focus on the near reading target that is assigned. The reading target is moved toward the eyes and stopped once the target is no longer able to remain in sharp focus. The distance from the eyes to the reading target is measured in metres (m) and the reciprocal of the distance measured will represent the AoA in diopters (D) (Wold et al., 2003). A Royal Air Force (RAF) rule (Figure 4) is the most regularly used instrument for conducting the push-up test. Although being commonly utilised, the push-up test does have certain sources of error to consider.

The accuracy of the push-up tests has been studied previously and was found to constantly provide higher AoA results compared to the objective method (Rosenfield and Cohen, 1996; Wold et al., 2003; Wolffsohn et al., 2011). It was suggested that the higher results obtained from the subjective push-up method may be due to factors such as the accommodative pupil size which increases the depth of field, lighting, the size of the test target and subject variability (Rosenfield and Cohen, 1996; Wold et al., 2003; Wolffsohn et al., 2011).

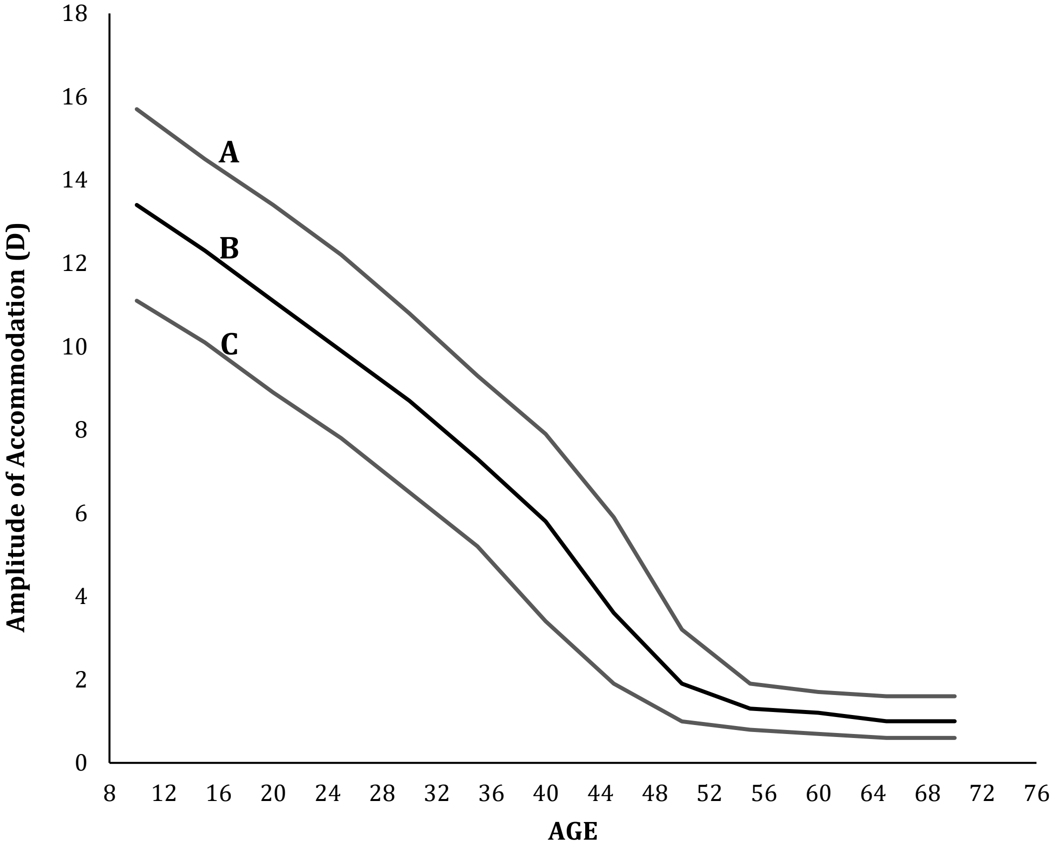


Figure 3. Duane’s (1922) standard curve of accommodation in diopters in relation to age (A: maximum values; B: mean value; C: minimum value). Graph redrawn based on the amplitude of accommodation value by Duane (1922).

The reaction time of the subject and the examiner may be another source of error that caused the higher results for any form of test that required movement of the targets for measuring the AoA. Burns et al. (2014) in their review concluded that it is the sum of four reaction times that happened altogether because the test target moves past the point where the first noticeable blur occurred. The four reactions that they refer to are: the time taken for the subject to notice the blurring of the target; the time taken to inform the examiner that blur has been detected; the time taken for the examiner to register the alert and the time taken for the examiner to stop the movement of the target. Although many suggestions have been made to reduce the error created by reaction time during measurement of the AoA, no actual recommendation has been introduced until now (Adler et al., 2013; Allen and O'Leary, 2006; Atchison et al., 1994).

Indication of reference point during AoA measurement is also important as it can affect the result, particularly at higher levels of the AoA (Burns et al., 2014). For example; if based on Duane's measurement reference point, it is 14 mm in front of the eye while Donder's measurement reference point is 7 mm behind the anterior corneal pole. Therefore, if 1 D of the AoA was measured using Donders' reference point, then Duane's reference point will be recorded as 1.02 D, which is not significantly different. However, when the level of the AoA is increased to 10 D based on Donders' reference point recording, Duane's reference point will provide a value of 12.66 D (Burns et al., 2014).

Instrumentation error may also occur due to the different positions of the slider's index on the scale of the RAF rule and the uncertainty of the zero-point position, causing variation in the value obtained using a different type of RAF rule scale (Burns et al., 2014).

Even though over-estimation may occur in the subjective accommodation amplitude test method, it is still one of the most commonly used methods in both clinical applications and research (Burns et al., 2014; Wolffsohn et al., 2011).

Figure 4: The RAF rule used for conducting the push-up test for measuring AoA.

2.2 Lag of Accommodation

During close work, there may be an error in the accommodative response. When the accommodative response is less than the demand that is required, there is an under-accommodation condition; this is known as the lag of accommodation (Gross et al., 2012; He et al., 2005; Rouse, 1982; Scheiman and Wick, 2014). Lag of accommodation is believed to arise from the imperfection in the neural integrator in the accommodation control system (Charman, 1999) and when the distance of the target focus objects to the eyes decreases, there is an increase in the amount of lag of accommodation

(Charman, 1999; Gwiazda et al., 1993; Gwiazda et al., 2004; McBrien and Millodot, 1986; Nakatsuka et al., 2005).

Lag of accommodation is commonly seen clinically in normal asymptomatic people at a close reading distance of +0.50 D (± 0.25 D) during binocular viewing (Wolffsohn et al., 2011). This situation would mean that most of the time, an individual is constantly not focusing correctly on the near target but instead slightly behind the target of interest.

A high lag of accommodation is said to be present when the amount of lag of accommodation found is higher than the value that is mentioned above. With higher accommodative lag, the focus is brought further away (behind) the reading material. Emslie et al. (2007) mentioned that higher lag of accommodation could result from accommodative dysfunction, such as accommodative insufficiency, fatigue, paresis and/or infacility. Hyperopia or latent hyperopia, near esophoria, poor divergence ability at near distances or over-correction of distance prescription can also cause a higher lag of accommodation.

However, many people may not be aware of the presence of blurred vision at near. Chung et al. (2007) showed that most of the time reading speed is not affected by the effect of blur, even up to 2 D of blurred vision during near work. It has also been shown that with sufficient spatial frequency information within the low-pass-filter text, the efficiency in reading is not affected even when the text image is blurred (Chung et al., 2007; Legge et al., 1985). However, this study contrasts with that of Sohrab-Jam (1976).

In the latter study, the eye movement of 38 young subjects, aged 9–11 years, who were behind grade level in reading achievement was observed. Nineteen subjects with a higher lag of accommodation finding, showed improvement in their reading rate and better fixation with a +0.50 D correction; this would mean that lag of accommodation does affect close reading work. The accommodative lag finding was based on book retinoscopy, which is a type of dynamic retinoscopy used to determine the change in accommodation while an individual is reading a book (Pheiffer, 1995; Sohrab-Jam, 1976). Book retinoscopy is conducted behind the reading material with patients wearing their full distance refractive correction. The examiner will observe and neutralise the movement of the retinoscope light reflex using trial lenses inserted into the trial frame, which is similar to how a standard retinoscopy is conducted.

Since the slightly blurred vision is still within the depth-of-focus of an individual, there are no symptoms. Although it was known that when objects are brought closer to the eye, it inevitably increased the amount of lag of accommodation, which may result in blurry vision. However, Charman (1999) reported that even with an increase in the lag of accommodation when a young observer brings the object of interest closer, it did not make the object more difficult to see. In fact, it made it easier to see the fine spatial detail of any particular linear scale and suggested that this phenomenon is due to the diffraction cut-offs and the characteristics of the neural system.

Lag of accommodation can be measured using dynamic retinoscopy. This method can quantify the amount of lag of accommodation by determining the refractive state of an accommodating eye (Hinkley et al., 2014). The three most common clinical dynamic retinoscopy methods to determine the amount of lag of accommodation include: Monocular Estimate Method (MEM) retinoscopy, Nott Retinoscopy (NR) and Bell Retinoscopy (BR). Because this thesis uses MEM retinoscopy to determine the lag of accommodation for the participants, discussion of dynamic retinoscopy will focus on MEM retinoscopy (section 2.4.6).

2.2.1 Myopia and Lag of Accommodation

Although it is common for an individual to have a lower accommodative response to the accommodative stimulus, refractive status and binocular muscle alignment for near work also contributes to the amount of lag of accommodation that is observed (Gwiazda et al., 1993; Gwiazda et al., 1999; Gwiazda et al., 2004). Many studies (Gwiazda et al., 1993; Gwiazda et al., 2004; Gwiazda et al., 2005; Koomson et al., 2015; Koomson et al., 2016; McBrien and Millodot, 1986; Nakatsuka et al., 2005) had been conducted to compare the amount of lag of accommodation between emmetropic and myopic status. Gwiazda et al. in their studies (1993; 1999; 2004; 2005) on myopia progression have indicated that myopes exhibit a larger lag of accommodation compared to emmetropic children in association with near work. When the accommodative demand increases, the amount of lag of accommodation also increased (Gwiazda et al., 1993; Gwiazda et al., 2004; McBrien and Millodot, 1986).

Koomson and colleagues' (2015; 2016) with myopic children aged from 10–15 years also indicated that myopic children demonstrate a certain amount of lag of accommodation at near distances. In the study, all the myopic children, whether in the full distance correction or under corrected group, showed a lead of accommodation at far distances and lag of accommodation at near, with the children in the full correction group showings a higher lag of accommodation. Nakatsuka and colleagues (2005) also reported that with full distance refractive correction, the myopic children in their study showed a larger mean lag of accommodation compared to emmetropic children.

Bao and co-workers' study (2013) to determine whether addition lenses play a role in the retardation of the progression of myopia also reported that myopic children have a higher lag of accommodation (1.35 D) compared to emmetropic children (0.86 D) at a test distance of 33 cm.

Explanations as to why myopes have a higher lag of accommodation compared to emmetropes are incomplete. Gwiazda et al. (2005) reported that pre-myopic children show an increase in the lag of accommodation two years before myopia onset. However, Mutti et al. (2006) reported that lag of accommodation is not elevated in pre-myopic children until the onset of myopia. Although there is no agreement on whether lag of accommodation is elevated before or after the onset of myopia, many reports have indicated that the accommodative lag is present in myopic adults or children and is higher than the emmetropes (Gwiazda et al., 1993; Gwiazda et al., 2004; Gwiazda et al., 2005; Koomson et al., 2015; McBrien and Millodot, 1986).

One particular study by Rosenfield et al. (1999) indicates that the sensitivity to presences of blurred for myopic eyes is reduced and this reduction in sensitivity might explain why a larger lag of accommodation is observed.

2.2.2 How Lag of Accommodation can be Reduced

With the presence of lag of accommodation, a certain amount of focusing inaccuracy occurs for the near target; this can be reduced by introducing plus power correction for near tasks. It has been shown that by introducing plus powered lenses or under correcting the myopic distance prescription can reduce the amount of lag of accommodation (Bao et al., 2013; Gwiazda et al., 2004; Koomson et al., 2015; Koomson et al., 2016; Rosenfield and Carrel, 2001).

Koomson et al. (2015; 2016) reported that when myopic children were under corrected, the amount of lag of accommodation found was lower than those who were fully corrected. Nakatsuka and colleagues (2005) also showed that when under binocular viewing conditions, myopic children show larger lag of accommodation compared to emmetropic children and this amount of lag of accommodation can be reduced to the level found in the emmetropic group by spectacle under correction.

Gwiazda et al. (2004) used progressive addition lenses (PALs) to slow myopia progression and indicated that the lower myopic power in the PALs resulted in a lower lag of accommodation in their subjects compared to single vision lenses. Rosenfield and colleagues' (2001) experiment on the effect of PALs on the accuracy of accommodative response demonstrated that the near addition power of PALs, which is similar to a reduction of the distance refractive correction in myopes, could affect the lag of accommodation. In the experiment, although all subjects did not present with lag of accommodation, a shift in the lead of accommodation during binocular viewing of near targets was found when near addition power was introduced over their distance correction and a larger lead of accommodation was observed with a higher amount of near addition power.

Bao and colleagues' study (2013) on retardation of myopia using addition lenses also indicated that lead of accommodation was observed when a +3.00 D near addition lens was applied to the distance correction of their myopic subjects, who displayed a lag of accommodation initially.

Even though all the studies (Bao et al., 2013; Gwiazda et al., 2004; Koomson et al., 2015; Koomson et al., 2016; Nakatsuka et al., 2005; Rosenfield and Carrel, 2001) mentioned above were conducted on children, a study by Haghi (2015), which was conducted on 132 subjects, aged between 12 – 25 years, has also reported that myopic adults exhibit higher accommodative lag when compared to emmetropes. Jiang et al. study (2007) has also shown that by using plus power lenses, it can reduce the amount of accommodative lag in adults.

Therefore, regardless whether in children or adults, a higher lag of accommodation can be observed in myopes as compared to emmetropes. Also, by adding near addition (plus power), it can reduce the amount of lag of accommodation found and thereby decrease the amount of retinal defocus.

2.3 Relative Accommodation

The total amount of accommodation that the eye can exert while the convergence of the eyes is fixed is known as relative accommodation. It can be either positive relative accommodation (PRA) or negative relative accommodation (NRA) (Morgan, 1944).

The relative accommodation test was designed as part of the near point test to evaluate the accommodation and binocular vision of an individual. This test is conducted by adding lenses over the full distance prescription in 0.25 D steps binocularly while the eyes fixate at a detailed target at a constant distance of 40 cm. In most cases, the test is preferred to begin with positive lenses (Scheiman and Wick, 2014; Yekta et al., 2017), and +0.25 D lenses are added until the subject is no longer able to see the target clearly and the test is completed; this finding is known as NRA. Using the same full distance prescription, -0.25 D lenses are added in steps similar to the NRA testing and the test is completed when the subject could not maintain the target clearly; this finding is known as PRA.

The test mainly uses positive or negative lenses to change the accommodative response while maintaining the vergence within the Panum fusion area. When plus lenses are added to the fully corrected distance prescription, besides causing the accommodation to relax, it also causes the eyes to diverge. To maintain clear single binocular vision, the eyes will need to converge to return the target to the centre of the Panum fusional area; this is achieved by using the positive fusional vergence (PFV). Therefore, it will reach a point where the eyes being relaxed by the plus lenses will no longer be able to maintain a clear binocular single vision because the amount of PFV is no longer enough to compensate for the divergence induced by the plus lenses, and the subject will report sustained blurred vision. The opposite will occur when minus lenses are added and the accommodation is being stimulated, which causes convergence of the eyes. The eyes will be required to diverge using the negative fusional vergence (NFV) to maintain a clear single binocular vision with the object in the centre of the Panum fusional area. This observation shows that the relative accommodation test not only tests the amount of accommodation that can be relaxed or stimulated while the eyes are converged and fixated on a target, but also indirectly tests the PFV and NFV ability of the eyes.

Because the test target is placed at a distance of 40 cm, the expected amount of accommodation required to keep the target clear will be 2.5 D. Therefore, the maximum amount of accommodation that can be relaxed will be expected to be 2.5 D. Thus, the expected finding of NRA is +2.5 D (Scheiman and Wick, 2014). In pre-presbyopic individuals, it is expected that NRA and PRA findings should be approximately balanced. However, there is no consistent endpoint for the maximum value of PRA. The endpoint of PRA will depend greatly on an individual's AoA, NFV and the accommodation convergence and accommodation (AC/A) ratio.

	Subject A	Subject B
Amplitude of accommodation (D)	15 D	15 D
AC/A ratio	3:1	5:1
Base-in vergence (Near)	12 / 20 / 12	10 / 20 /10
Expected PRA value (D)	- 4 D	- 2 D

Table 1: Example illustrating the variables that affect the endpoint of PRA.

For example: Subjects A and B AoA, AC/A ratio and base-in vergence are listed in Table 1. In this case, Subject A will be able to keep the target single and clear until it reaches - 4 D. As minus lenses are constantly being added binocularly, Subject A will be required to keep the target clear and this will not be a problem because the AoA is 15 D. However, with accommodation, convergence resulted and the amount of convergence will depend on the AC/A ratio, which in this case will be 3 prism diopters (△) with every 1 D of accommodation. To maintain a clear single vision of the target, subject A will need to use the NFV to counter the convergence that resulted from the accommodation. Since Subject A has 12 △ of base-in fusional reserved, blurring of the target will only occur when minus power up to -4 D is added.

Based on the same theory, Subject B will have a lower PRA value of - 2 D because the AC/A ratio is higher than Subject A while the fusional reserved is lower, even though the AoA is the same.

Therefore, the endpoint of PRA is affected by multiple factors. The main objective of conducting the relative accommodation test is to determine whether NRA and PRA are balanced. Scheimen and Wick (2014) in their book indicated that the expected value for NRA should be + 2.00 D (SD 0.50 D) and for PRA, it should be – 2.37 D (SD 1.00 D).

With low NRA findings, it would mean that the eyes are unable to accept the plus lenses either because the accommodation cannot be relaxed, which may be due to accommodative excess, or the ocular system has an inadequate PFV that is insufficient to counteract the amount of divergence resulting from the relaxation of accommodation due to the plus lenses, which may indicate convergence insufficiency. In low PRA findings, it would mean that the eyes are unable to accept the presence of the negative lens power, either because the eyes cannot increase the accommodation to meet the same value as the added negative lenses, which may be due to accommodative insufficiency, or that there is an insufficient NFV to counteract the increase in the convergence resulted from the increase in accommodation due to the negative lenses induced, which may indicate the presence of convergence excess (García et al., 2002).

Hokoda (1985) indicated that a low PRA finding of ≤ 1.25 D is used as one of two supplementary signs that should be present in diagnosing accommodative insufficiency. Scheiman et al. (1996) also stated that the PRA finding is used for accommodative dysfunction diagnosis and that a low NRA value of < 1.50 D is linked to convergence insufficiency. García et al. (2000) and Lara et al. (2001), in their studies, reported that a low PRA value of ≤ 1.25 D is used for diagnosis of accommodative insufficiency and convergence excess, while a low NRA finding of ≤ 1.50 D is used for diagnosing accommodative excess and convergence insufficiency diagnosis.

However, use of the relative accommodation test alone may not be sufficient as a diagnostic test for binocular dysfunctions. Other binocular tests should also be incorporated, because the anomalous value in the relative accommodation test cannot specifically diagnose the particular dysfunction the eye is experiencing.

2.4 Binocular Testing

2.4.1 Heterophoria

Heterophoria, commonly known as phoria, is the misalignment of the eyes visual axes; this can occur during dissociation of the eyes, resulting in the absence of the disparity cue that is used in the fusional vergence to correct the misalignment thereby causing the eyes to move into the heterophoria position (Dowley, 1990). Heterophoria is measured in prism diopters (Δ). Each prism diopter is equivalent to 0.57 degrees of deviation (Babinsky et al., 2015). Heterophoria can occur in either horizontal or vertical conditions. For this thesis, only the horizontal heterophoria will be discussed.

When the misalignment of the eyes is in a divergent direction, it is known as exophoria, while a deviation in the convergent direction is known as esophoria. When no deviation or a minimal of < 2 Δ is present, it is defined as orthophoria (Hokoda, 1985). Based on several studies (Babinsky et al., 2015; Eames, 1933; Evans, 2009; Hirsch et al., 1948; Morgan, 1944; Tait, 1951), the average distant phoria for an adult range from 0 to 1 Δ (SD = 2 Δ) of exophoria. When fixation is changed to the near target, convergence of the eyes occurs and this subsequently causes changes to the vergence and accommodation demand. These changes are induced by retinal disparity, blur and/or knowledge of perceived distance change (Goss and Zhai, 1994), previously described by Maddox (1886) and Heath (1956). The average heterophoria for an adult when viewing an object at 40 cm is about 3 to 5 Δ of exophoria (Babinsky et al., 2015; Eames, 1933; Evans, 2009; Hirsch et al., 1948; Morgan, 1944; Tait, 1951).

Heterophoria is classified as compensated if the individual is asymptomatic; this happens when an individual's fusional vergence is strong enough to compensate or overcome the deviation. When the fusional vergence is unable to compensate enough for the deviation, it is known as decompensated phoria and can result in visual symptoms ranging from vision (e.g. blurred vision), binocular factor (e.g. difficulties with focusing) and asthenopia (e.g. headaches, aching around the eyes, etc.) (Evans, 2009).

2.4.2 Methods to Test for Heterophoria

Heterophoria can be measured using different clinical techniques. Most of the techniques apply the theory of dissociation, which is achieved by introducing two different or dissimilar targets to each eye. Individuals undergoing these tests are usually asked about the position of the image seen with one eye and compare the position of the image to other eye (Evans, 2009). Heterophoria testing is usually conducted for both distant and near conditions.

Some of the commonly used clinical methods to measure distant heterophoria include:

1) Maddox Rod

- This test can detect both horizontal and vertical heterophoria amounts. In this test, a red lens with deep grooves ground into the lens is placed in front of one eye and a spotlight is shone from a distance. The red lens will distort the light, creating a line while the other eye sees the spotlight. To test for horizontal heterophoria, the red lens is placed with the grooves horizontally, which will create a vertical line seen in one eye. The individual is asked for the relative position of the line with respect to the spotlight.

  For example, when the red lens is placed in front of the right eye (RE), the RE will see the vertical line. Therefore, under the esophoric condition, there is an uncross diplopia and the vertical line will be on the right side to the spotlight seen with the left eye (LE), as shown in

Figure 5. The opposite will occur for the exophoric condition where there is a cross diplopia; therefore, the line will appear to the left of the spotlight seen with the LE. Once this position is known, the prism can be introduced in front of either one or both eyes to shift the image until the line passes through the light. The amount of prism required to shift the line and spotlight to alignment is the amount of heterophoria the eyes are experiencing (Evans, 2009).

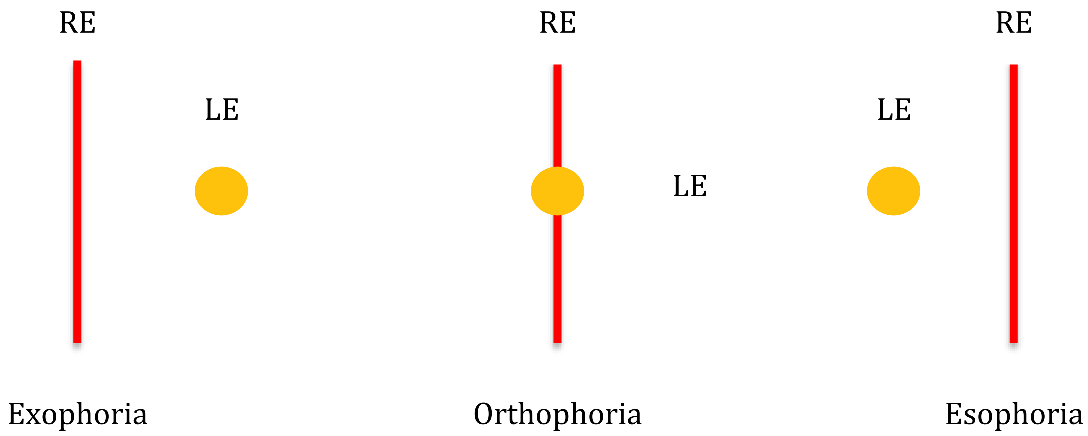


Figure 5. Example of the Maddox Rod test, with the red groove lens located in front of the right eye (RE) and the spotlight seen with the left eye (LE).

2) Modified Thorington Technique

- This test method is very similar to the Maddox Rod test but incorporates a scale chart. The red groove lens is placed in one eye while both eyes fixate on a chart with horizontal and vertical scales (Figure 6). A light source is shone from the small hole in the centre of the chart, thus creating a line. The amount of heterophoria is read from the chart. When testing horizontal heterophoria, the red groove creates a vertical line similar to the method used in the Maddox Rod test. The number and the direction that the light cuts across will be the prismatic amount of heterophoria that is present (Evans, 2009; Scheiman and Wick, 2014).

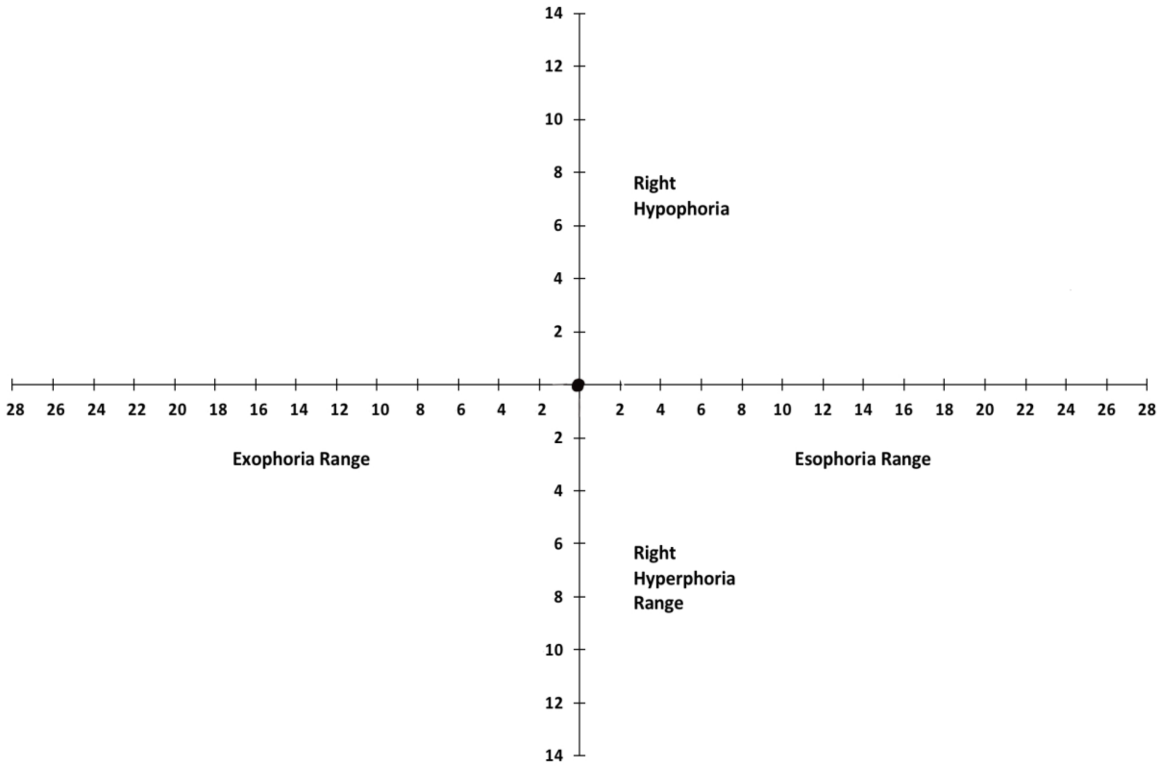


Figure 6: Chart used in the Modified Thorington Technique (redrawn). When the light appears on the left side of the horizontal scale, it indicates exophoria and to the right of the scale, it indicates esophoria.

3) Von Graefe Test

- In this test, prisms are used to dissociate the eyes and create a diplopic image. A single isolated letter is presented to the individual with VA one line larger than the worse eye. A 6 Δ base-up prism is placed in front of one eye, which will split the image and create a vertical diplopia. The individual is asked to fixate on the bottom letter and report the position of the top letter with reference to the bottom letter; for example, the top letter is to the right or to the left of the bottom letter. Under the esophoric condition, there is uncross diplopia and in the exophoric condition, there is cross diplopia. Once the direction of the heterophoria is determined, the prism can be introduced to the eye without the split prism and shift the top letter until both letters are aligned one on top of the other (Evans, 2009; Scheiman and Wick, 2014).

For measurement of near heterophoria, some of the common clinical tests are:

1) Maddox Wing

- Near phoria can be measured using the Maddox Wing instrument. The Maddox Wing is a hand-held device that is used to measure the amount of near heterophoria at a distance of 33 cm, using the principle of dissociation of fusion by a dissimilar object. The instrument comprises a lightweight matt-black plastic frame, which has a handle for the participant to hold the instrument. At one end of the instrument, there is a two-hole viewing eyepiece and the other end consists of a black plate with a matt-printed scale card. An individual holds the Maddox Wing with full distance refractive prescription in place while viewing through the two eyepieces, at an angle approximately 15^0 downward. The view is separated using a septum; the RE sees the white arrow pointing vertically upwards while the LE will see a scale in white print horizontally above the arrow, that is calibrated in diopters of deviation (1 Δ = 3.3 mm at 33 cm) (Figure 7). If there is no misalignment of the ocular muscle at near ranges, the white arrow will point to zero on the number scale. If there is presence of horizontal heterophoria, the arrow will shift towards the right to indicate the esophoric condition and to the left for the exophoric condition. The number reported is recorded as the near heterophoria finding (Pointer, 2005).

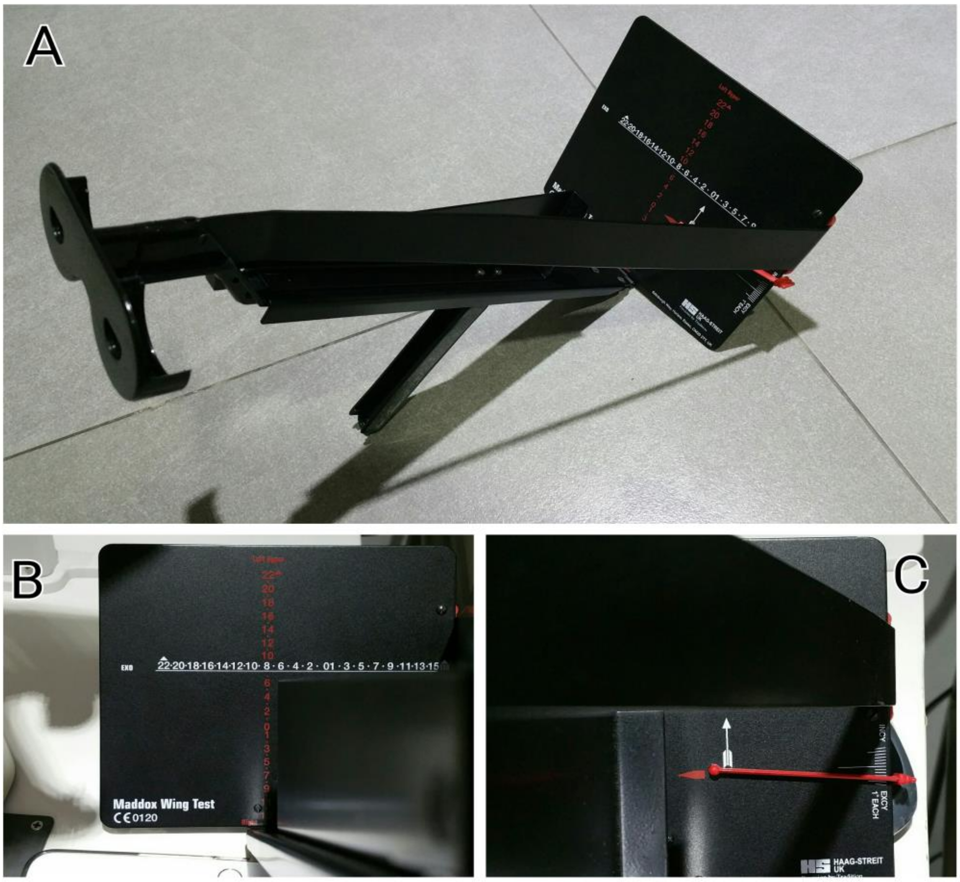


Figure 7: Maddox Wing used for the near phoria test. A) Full view of the Maddox Wing. B) View of the scale from the LE pieces. C) View of the white arrow from the RE pieces.

Other tests, such as the modified Thorington and Von Graefe techniques that were described previously, can also be used to measure the amount of near heterophoria (Evans, 2009). However, due to the commercial availability and the convenience of detecting and measuring of decompensated heterophoria, the Maddox Wing is one of the most commonly used techniques for near phoria measurements in most optometric consultation rooms, even in the UK (Pointer, 2005).

In this thesis, the Von Graefe technique was used for distance phoria and the Maddox Wing was used for near phoria measurements. These two tests were chosen because of the availability in most clinical set ups. It was reported in studies that different phoria measurement techniques may produce varying results (Eames, 1933) and that the techniques are not interchangeable (Sanker et al., 2012). Therefore, it cannot be concluded as to which technique is the most accurate or more useful (Maples et al., 2009). Rather, it must be noted that differences in measurement may occur depending on the technique used. Therefore, in the repeated measurement test, the same testing technique should be used to avoid errors in the results.

Factors that may cause variation in the phoria measurements include test distance and target size. Chen and Aziz (2003) indicated that when the viewing distance of the target increased, the amount of heterophoria reduced towards orthophoric. The study was conducted for near phoria testing, but this finding may also be applied for distance testing. Therefore, viewing distance during phoria measurement should be kept constant, particularly when repeating the measurement at different clinical sessions. Sanker et al. (2012) also reported that when the target size changes, it might produce a significant change to the accommodation required; thus, affecting the heterophoria result. Therefore, control of accommodation during the heterophoria test is very important.

Casillas and Rosenfield (2006) have also highlighted that when conducting heterophoria measurements at near and far distances, using a trial frame will produce more repeatable results than using a phoropter in the clinical setting. They proposed that when using the phoropter to conduct near horizontal heterophoria testing, it creates a limited field of view through the phoropter whether it is monocular (about 25^0 field of view) or binocular (about 30^0 field of view), compared to the trial frame where there is only a ring scotoma created by the frame edge. Also, peripheral vision is not restricted in the trial frame condition; therefore, there is a possibility that peripheral fusional stimuli is present even during dissociation conditions, which can influence the eye position during heterophoria testing using the trial frame, thereby producing a more stable vergence response.

2.4.3 Heterophoria and Accommodation

Although heterophoria is a misalignment of the ocular visual axis during the absence of fusion, compensation occurs during binocular viewing by means of fusional vergence to maintain clear single vision. The direction and amount of fusional vergence (convergence or divergence) to maintain binocular single vision will depend greatly on the size and type of heterophoria (exophoria or esophoria) that the individual is experiencing. It was found that the presence of exophoria results in an increase in the shift in convergence of the eyes to compensate for the deviation, and a shift in the divergence direction occurs with the presence of esophoria (Sreenivasan et al., 2012).

Due to the synergistic connection between the vergence and accommodation system, during the activation of fusional vergence to compensate for the heterophoria, it also results in a change in the accommodation response (Hasebe et al., 2005; Schor, 1999). For the exophoria condition, a compensation shift in the convergence direction will indirectly cause the eyes to increase the accommodation. The opposite will happen for the esophoric condition where the divergence of the eyes is required and, therefore, causes the eyes accommodation to relax.

The Schor report (1999) on the influence of heterophoria on accommodation response predicted that heterophoria can cause large accommodation errors and indicated that uncorrected hyperopia with esophoria participants show an increase in the lag of accommodation while uncorrected myopia with exophoric participants show a decreased lag of accommodation, or even crossing over to lead of accommodation while viewing a 40 cm target. It was also indicated that this condition is directly linked to the AC/A or the convergence accommodation/accommodation (CA/C), because when both the AC/A and CA/C ratios were increased, the effect of the change in accommodation was also increased.

Hasebe and co-workers' study (2005) on the accuracy of accommodation in heterophoric patients also shows that the phoria condition caused an increase in the accommodation error. The authors found that the accommodation lag under the monocular condition was higher for the exophoric group when compared to the esophoric group. However, during binocular condition, the amount of lag of accommodation was decreased in the exophoric and orthophoric group while the esophoric group showed an increase in the lag of accommodation. The result shows that under the monocular condition, there is an absence of fusion condition. However, when binocular viewing is allowed, the heterophoria will require compensation by fusional vergence. The authors also indicated that under the exophoric condition, if the phoria condition is large enough, it can exceed the physiological accommodative lag and cross over to become accommodative lead; whereas in the esophoric condition, if the esophoria is relatively large, the accommodative lag may increase and result in an individual experiencing severe astheopia.

2.4.4 Accommodative Convergence to Accommodation (AC/A)

The Maddox classification of vergence consists of four elements. One of the elements is the accommodative vergence, which occurs due to the synergistic condition between accommodation and vergence, resulting in changes to the horizontal alignment of the eyes (Heath, 1956). This type of change requires the accommodative effort and therefore is considered to be due to the blur-driven condition. The total amount of changes to the vergence created by each diopter of accommodation is represented by the AC/A ratio and is expressed in prism diopters per diopter (Rainey et al., 1998).

There are various ways to measure the AC/A ratio. One of the more common clinical methods is the gradient method, also known as the stimulus AC/A ratio. This test causes changes to the accommodation not by varying the viewing distance but by stimulating the accommodation using ophthalmic lenses. For example, with a given fixation distance, minus lenses of 1 D are placed before the eyes and this requires the eyes to accommodate 1 D to maintain the clear image. Due to the accommodation, it results in changes to the vergence. Comparing the original vergence with the stimulated vergence based on the 1 D of accommodation, the difference between them is determined to be the AC/A ratio. This difference deduced based on a simple formula:

$$AC/A = \Delta_2 - \Delta_1 / D,$$

where Δ_1 represents the original deviation, Δ_2 is the deviation created by the ophthalmic lenses and D is the power of the ophthalmic lenses used.

The AC/A ratio can be easily measured during a heterophoria test using the Maddox Wing test (Evans, 2009). After measuring the amount of heterophoria of an individual, ophthalmic lenses can be inserted in front of the eyepieces of the Maddox Wing instrument. This procedure will cause a shift to the white arrow and a new number will be reported. For example, the initial amount of phoria is 4 Δ esophoria and when a -1 D lens is inserted, the arrow shifts to 9 Δ esophoria; therefore, the AC/A ratio will be 5 Δ/1 D.

It must be noted, however that the AC/A ratio may fluctuate; therefore, it may not be accurate based on one measurement. This observation is because in the gradient AC/A method, it is assumed that the accommodation response is equal to the stimulus, but in many cases, a mismatch between the accommodative stimulus and accommodative response can be present, which can affect the actual measurement of the AC/A ratio (Le et al., 2010). Consequently, effort in controlling the accommodation is essential by ensuring that clear vision is maintained while viewing through the stimulus lenses. An average of the AC/A ratio from three measurements should be obtained, rather than just depending on a single measurement result.

2.4.5 Fusional Vergence

Fusional vergences are important to maintain the alignment of the eyes so that there is a similar image of the object projected onto the corresponding retinal area, which is a requirement for single binocular vision. Fusional vergences are classified into three different directions according to the plane of eye movements: horizontal (convergence and divergence), vertical and rotary (Evans, 2009). In this thesis, focus will be on the horizontal fusional vergence.

When heterophoria is present, there is a certain amount of misalignment of the eyes and this requires the individual’s fusional vergence to compensate for the misalignment so that there are no visual symptoms of blurriness or diplopia (Evans, 2009). The fusional vergence range an individual has can be measured by inducing a prism in front of the eyes under binocular conditions with the accommodation demand held constant. By inducing a base-out prism, it creates convergence (positive fusional vergence) while a base-in prism will create divergence (negative fusional vergence). A prism bar is usually used to conduct the fusional vergence test and it was suggested that the fusional vergence that is opposite to the heterophoria should be tested first (Evans, 2009; Scheiman and Wick, 2014). A detailed fixation target is placed at 40 cm, while a prism is introduced in front of one of the eyes. The amount of prism is increased slowly, and the participant is instructed to report when the target is blurred or becomes diplopic (break). Once diplopia is observed, the prism is gradually reduced until the fixation target becomes single, and this will be the recovery point. The fusional vergence range is recorded as blur/break/recovery (Evans, 2009; Scheiman and Wick, 2014). It was reported (Sreenivasan et al., 2016) that the mean fusional vergence break points of an adult for a 40 cm viewing distance is about 18 to 23 Δ for divergence and approximately 19 to 25 Δ for convergence.

Besides compensating for heterophoria, as seen in relative accommodation (section 2.3), fusional vergence is also important in maintaining a clear single binocular vision by compensating for the amount of eye movement in the opposite direction (Evans, 2009; Scheiman and Wick, 2014); this factor, along with the AC/A ratio, will affect the amount of PRA found during the relative accommodation testing. Therefore, relative accommodation is also considered an indirect test for fusional vergence (Evans, 2009; Scheiman and Wick, 2014).

2.4.6 Monocular Estimate Method (MEM) Retinoscopy

One of the most widely used clinical dynamic retinoscopy methods to assess the accommodative responses is the Monocular Estimate Method (MEM) retinoscopy (Gross et al, 2012; Scheiman and Wick, 2014).

MEM retinoscopy is conducted with patients wearing their full distance refractive correction and viewing a near reading target in the plane of the retinoscope. The examiner will observe the movement of the retinoscope light reflex from the horizontal axis and estimate the amount of prescription, either plus or minus, that is required to neutralise the movement. For the accommodative lag condition, a ‘with’ light reflex movement will be observed. Lenses are added in +0.25 D steps, in front of the patient’s eye and the movement is evaluated to confirm neutralisation. Lenses should not be placed in front of the eye for too long because it can cause relaxation to the accommodation and affect the accommodative response’s overall result (Scheiman and Wick, 2014).

The result obtained from MEM retinoscopy illustrates the difference between the accommodative stimulus and the accommodative response of the eyes (Cramer, 1853; Scheiman and Wick, 2014). The expected value of the MEM retinoscopy should be within 0 to +0.50 D (±0.25). Any value above this finding is considered to have a higher lag of accommodation (Gross et al, 2012; Scheiman and Wick, 2014).

The validity of MEM retinoscopy as a measurement of accommodative response has been shown by Rouse et al. (1982), who concluded that MEM retinoscopy is a useful clinical method to determine accommodative response. When the measurement was compared to a phoroaccommodometer, the results show a very similar accommodative stimulus up to 3 D for both. Other authors have also concluded that MEM retinoscopy can produce an accurate assessment of the accommodative response (Cooper, 1987) and has good inter-examiner reproducibility (McKee, 1981).

When comparing to another commonly used dynamic retinoscopy, Nott retinoscopy (NR), it was reported by Locke and Somers (1989) that both MEM retinoscopy and NR did not produce statistically significant differences in the results and therefore concluded that these techniques can be used interchangeably, but the same was not observed with Bell retinoscopy (BR). However, Del Pilar Cacho and co-workers' study (1999) disagreed with Locke and Somers results (1989), because the former's study indicated that the MEM retinoscopy resulted in a higher value of lag of accommodation, almost by a factor of two, as compared to NR. It was suggested that these differences might be attributed to the requirement for insertion of supplementary measuring lenses during MEM retinoscopy, during which the subject could have adapted to the effect of the inserted lenses, thereby producing an invalid result. Tassinari et al. (2000) cited in the Del Pilar Cacho et al. (1999) report regarding the differences in the results seen in the study and commented that such differences might be due to the equipment and the testing technique used during the MEM retinoscopy in their study. Also, the average accommodative response obtained using NR in their study (Del Pilar Cacho et al., 1999) was comparable with that of Locke and Somers (1989) results; therefore, both studies' results should be equivalent. Due to this condition, the conclusion on differences in the testing result between NR and MEM retinoscopy remains inconclusive.

A recent study by AlMubrad and Ogbuehi (2006) also considered whether NR and MEM retinoscopy can be used interchangeably. The research evaluated the accommodative lag on 130 normal subjects' REs and shows that there was no significant difference found between either technique, and therefore concluded that both dynamic retinoscopy methods can be used interchangeably and produce reliable estimates of the accommodative lag.

Based on multiple studies, it shows that MEM retinoscopy is a reliable method (Cooper, 1987; Rouse et al., 1982) with good repeatability (McKee, 1981) to determine accommodative lag of the eyes and is comparable to another commonly used clinical method, namely NR (AlMubrad and Ogbuehi, 2006; Locke and Somers, 1989; Tassinari, 2000).

2.5 Ocular Asthenopia

Asthenopia is a condition of multiple causes (Sheedy et al., 2003). For example: discomfort glare from lighting (American National Standards Institute, 1993; Guth, 1981); anomalies from an ocular binocular condition, such as esophoria, exophoria and convergence deficiency (Grisham, 1988;

Sheedy and Saladin, 1977; Sheedy and Saladin, 1978); accommodative condition, such as insufficiency or infacility (Hennessey et al., 1984; Jaschinski-Kruza and Schweflinghaus, 1992; Levine et al., 1985); poor contrast resulting in difficulties in viewing images affecting accommodative response (Sheedy, 1992); long hours of near work, especially with a computer (Murata et al., 1996); uncorrected ametropia (Wiggins and Daum, 1991; Wiggins et al., 1992) and dry eyes (Toda et al., 1993).

Among the many causes that can induce asthenopia, prolonged near work has always been a concern as a source of inducing visual problems and symptoms (Grisham et al., 1993; Owens and Wolf-Kelly, 1987). Murata et al. (1996) found that the symptom of asthenopia is not experienced by an individual immediately, but manifests over time. In their study (Murata et al., 1996), visual display terminal (VDT) workers were compared to non-VDT workers and it was found that long-term use of VDTs can result in a visual fatigue condition which may tend to accumulate over time.

Iribarren et al. (2001) conducted a study with 87 young subjects aged 18–31 years where the amount of near work, the accommodative facility and the intensity of the asthenopia were measured for each subject. It was reported that the cumulative effect of near reading affects the accommodative facility by decreasing it and increasing the asthenopic symptom. It also suggested that long hours of near work might cause mild accommodative spasm because of the sustained focusing condition at near stimuli over extended periods, leading to asthenopia. The finding of the study was consistent with other studies (Ciuffreda and Ordoñez, 1995; Ong and Ciuffreda, 1997) showing that near work-induced transient myopia (NITM) decayed slowly and irregularly in symptomatic subjects. Based on these studies, it may also indicate that because of the presence of NITM and the decrease in the accommodative facility, there can also be an increase in the accommodative lag at near distances.

Tosha et al. study (2009) examined the accommodation response and visual discomfort and reported that there was a significant increase in the amount of lag of accommodation in the high discomfort group compared to the low discomfort group, and proposed that this might be an indication of an accommodative fatigue effect rather than insufficiency. The study was conducted under the monocular condition, which eliminates the possibility of any binocular condition affecting the result.

Chase et al. (2009) also indicated that lag of accommodation is higher in symptomatic subjects when compared to the less symptomatic subjects. A strong correlation between symptoms of asthenopia and accommodative lag was also reported, showing that when accommodative lag increases, symptoms of asthenopia also increase.

Studies have shown that myopes exhibit a higher amount of lag of accommodation (Gwiazda et al., 1999; Nakatsuka et al., 2005) during near work. The higher amount of accommodative lag observed in myopic individuals was speculated to be due to the reduced steady-state accommodative response at near distances and the poorer blur sensitivity that was found in several studies (Ong and Ciuffreda, 1997; Rosenfield and Abraham-Cohen, 1999).

Therefore, as mentioned by Tosha et al. (2009), a higher amount of lag of accommodation may be an indication of accommodative fatigue and can cause symptoms of ocular fatigue. Myopes, who conduct long hours of near tasks and have a higher amount of lag of accommodation compared to emmetropic individuals (Gwiazda et al., 1993; Gwiazda et al., 2004; Gwiazda et al., 2005; Koomson et al., 2015; Koomson et al., 2016; McBrien and Millodot, 1986; Nakatsuka et al., 2005), may have an increase in lag after prolonged use of their eyes for near tasks and eventually develop symptoms of asthenopia.

2.6 Multifocal Soft Contact Lenses (MFSCLs)

MFSCLs have been available for many years and have developed many terms describing their design. The most common of such terms are ‘simultaneous image’ and ‘alternating vision’. Previously, the former term was used to describe the phenomenon of how MFSCLs could provide clear vision for both far and near distances. However, in a recent review reported by Pérez-Prados and colleagues (2017), the International Organization for Standardization (ISO) deprecated the term ‘simultaneous vision multifocal contact lens’. The organization defined the term ‘simultaneous image multifocal contact lenses’ to describe the phenomenon of MFSCLs.

Because most alternating vision designs are used in rigid gas permeable lenses instead of soft CLs and therefore, since the thesis focuses on MFSCLs, the alternating vision design will not be discussed in this thesis.

2.6.1 Simultaneous Imaging Design

Almost all commercially available CLs that are designed to provide near and far visual solutions for presbyopic patients, whether bifocal or MFSCLs are produced using a series of concentric zones or aspheric and bi-aspheric centre-distance or centre-near designs. All these designs incorporate the principle of simultaneous imaging, which creates superimposed near and far images within the visual system. The design requires the wearer to suppress the blurred image and choose the clearest image for the particular task (Pérez-Prados et al., 2017). The lens design requires the optical zones of the distance to near power progression to be fitted over the pupil (Figure 8) (Fedtke et al., 2017; Pérez-Prados et al., 2017).

The aspheric design (Figure 9) makes use of the theory of gradual change of curvature along either the front or the back surface of the CL to achieve a change in power from the centre to the peripheral lens; this will mean that the rate of flattening of these lenses is greater compared to a single vision lens (Bennett, 2008).

The aspheric design of the CL allows it to contain more plus in the centre of the lens, thereby creating a centre-near design. It is achieved by incorporating a front-surface aspheric design, which induces negative spherical aberration

(SA), resulting in more minus power towards the periphery from the centre of the CL (Bennett and Jurkus, 2005; Pérez-Prados et al., 2017). A centre-distance design can be achieved via inducing a back-surface aspheric design, which will create positive SA, resulting in decreasing the minus power from the centre to the periphery (Bennett and Jurkus, 2005; Pérez-Prados et al., 2017).

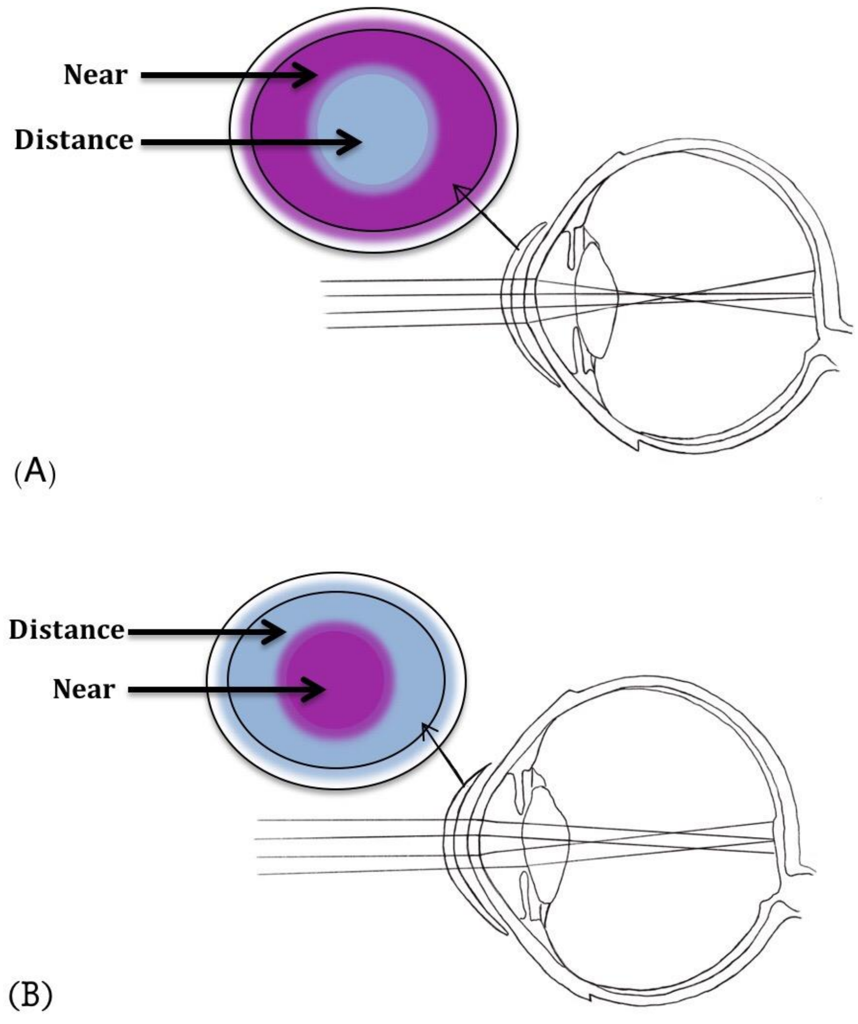
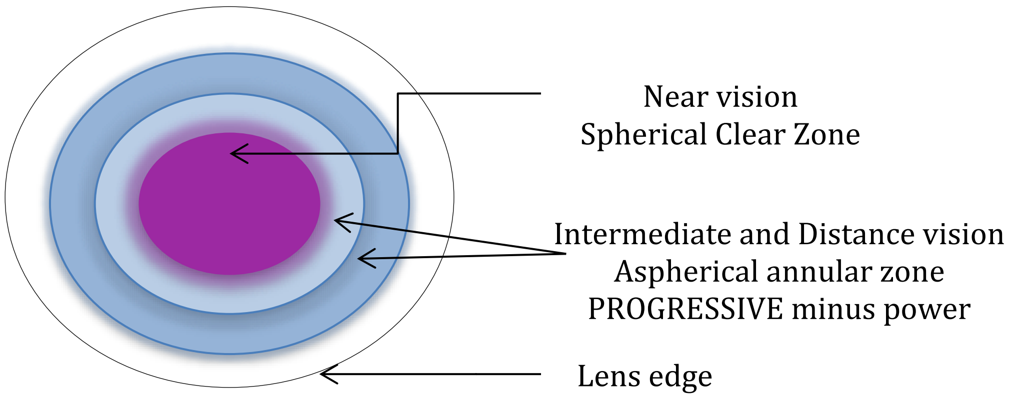
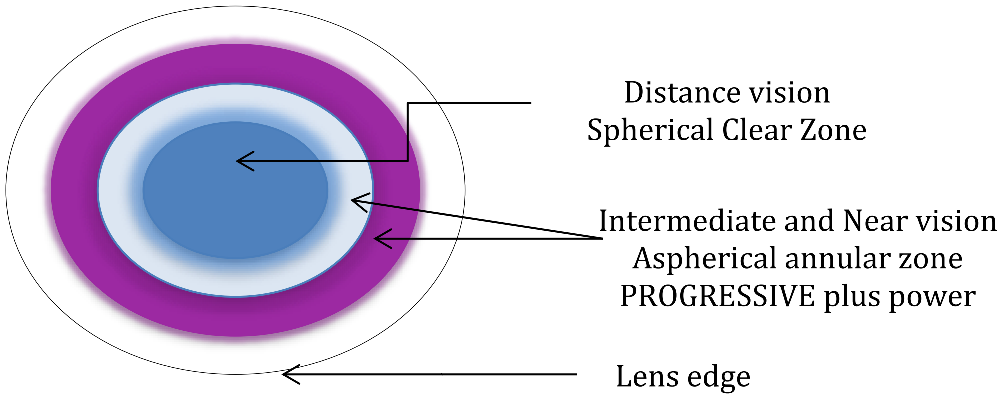


Figure 8: Principle of simultaneous vision design:
(A) Centre-distance design. (B) Centre-near design.
Diagram redrawn from: Contact Lens Practice: Special Lenses and Fitting Considerations, Presbyopia.



(A): Centre-Near Design



(B): Centre-Distance Design

Figure 9: Aspheric design: (A) Front surface aspheric centre-near design. (B) Back surface aspheric centre-distance design. Diagram redrawn from: https://coopervision.com/product-technology/balanced-progressive-technology).

A concentric design lens (Figure 10) is structured to have a zone of distance power and a zone of near power. Therefore, a centre-distance lens will have the optical zone of distance power in the centre and surrounded by a zone of near power, and vice versa.

The amount of clear distance or near vision depends on the diameter of the central segment of the designed lenses. For example, a centre-distance lens will allow a distant object to be clear most of the time but when the object is required to be near, the pupil constricts further, causing a reduced available near zone which reduces the clarity of the near object. With age, the pupil size reduces further, making it even more difficult to clearly see the near object. When the surrounding light illumination becomes dimmer, the pupil dilation results in a more near portion being seen and causes the distance vision to be blurred slightly; this shows that the concentric design is strongly pupil-size dependent (Gasson and Morris, 2010; Meyler and Efron, 2010). Concentric design is not commonly used in current manufacturing because of the availability of more successful aspheric designs of MFSCLs.

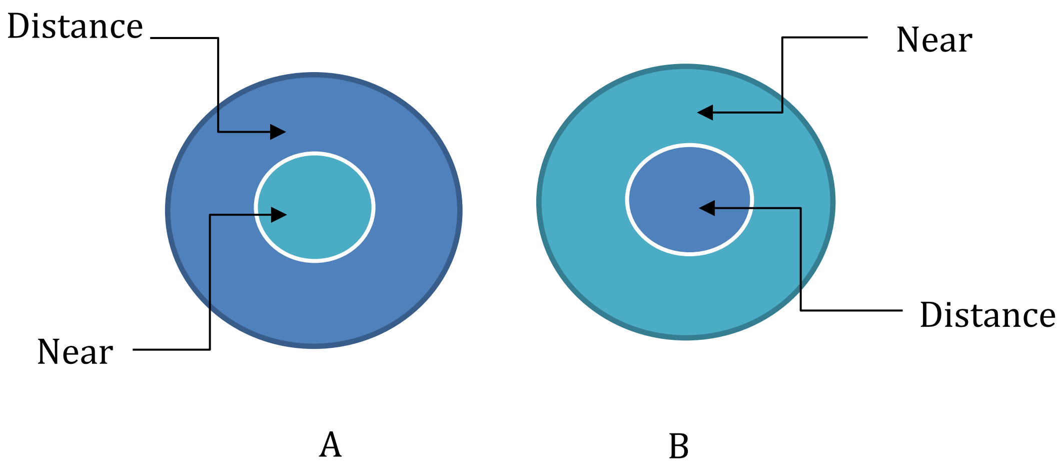


Figure 10: Biconcentric design: (A) Centre-near design, (B) Centre-distance design.

As previously mentioned, MFSCL will require multiple powers to be placed within the pupil zone of the wearer, thereby allowing light rays from near and far objects to be simultaneously imaged onto the retina, creating a constant combination of focused and defocused images simultaneously when looking at either near or far objects (Fedtke et al., 2017; Kollbaum and Bradley, 2014; Pérez-Prados et al., 2017). As the fixation of the target of interest changes from either far or near, one of the zones will produce a clear image on the macular, while the other a blurred image, which overlaps the same retina image (Benjamin and Borish, 1994; Pérez-Prados et al., 2017); this requires the individual to be able to suppress or ignore the blurred image and choose the clearer image (Pérez-Prados et al., 2017). Figure 11 shows an illustration of the result of the vision a wearer may experience when viewing through simultaneous vision design CLs.

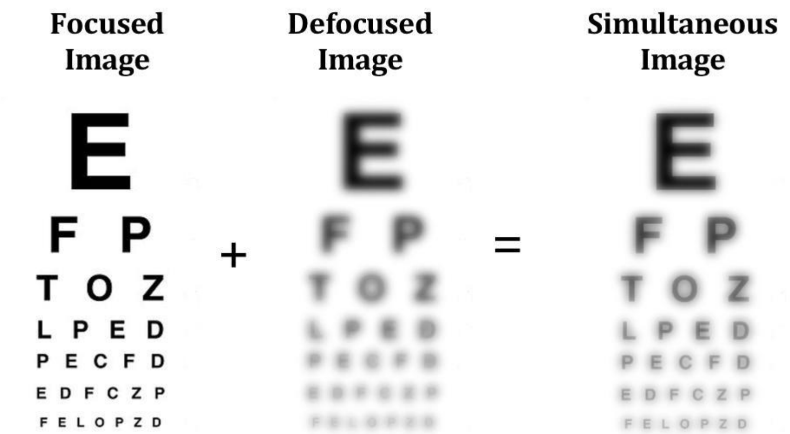


Figure 11: Illustration of the vision that an individual may experience with simultaneous vision contact lenses. Diagram redrawn from: Review of Cornea and Contact Lenses: A Clear View of Multifocal Contact Lens Optics; 2014.

Due to the multiple power designed within the optic zone of the MFSCL, it will require the lens to be fitted with good centration so that the correcting power of the lens will be located within the pupil region in all gaze positions. The distance and near portion of the lens area should also cover nearly the same area as the pupil, so that it will produce an image of equal brightness (Bennett and Jurkus, 2005).

If the MFSCL is decentred from the pupil centre, it can result in inducing unwanted aberrations, such as coma; this unwanted aberration can result in visual quality degradation (Kollbaum and Bradley, 2014). However, Fedtke et al. (2016a) examined the effect of decentred MFSCLs on the vision of presbyopic and non-presbyopic participants using six different MFSCLs. It was reported that decentration of the MFSCLs indeed induced certain amounts of third-order aberration, but vision was only significantly affected in the low-contrast visual acuity (LCVA) condition but not in the high-contrast visual acuity (HCVA) during decentration of the MFSCLs for the non-presbyopic group. Some MFSCLs were found to have decentred more than the others and the author suggested that this could be due to the difference in the lens design and fitting parameters.

2.6.2 Air Optix Aqua Multifocal Soft Contact Lenses (MFSCLs)

Air Optix Aqua MFSCLs are manufactured by Alcon (Alcon Laboratories, Fort Worth, US). Based on the product specification, they are simultaneous-imaging design lenses with a double-aspheric surface and a centre-near design. The material of the lens is lotrafilcon B and has a water content of 33%. The base curve for the lens is 8.6 mm with a total lens diameter of 14.2 mm. The lens power is available from -6.00 Ds to +4.00 D in -0.25 D steps and -6.50 D to -10.00 D in -0.50 Ds steps. Three different additional powers are available and based on the fitting guide, low addition is fitted for an added power ≤ 1.00 D, while medium addition is fitted for an added power between 1.25 to 2.00 D and the high addition is fitted for an added power > 2.00 D. Near and intermediate power is designed to be located in the portion of the optic zone, while the distance power is located in the portion surrounding it.

Montés-Micó et al. (2014) reported that Air Optix Aqua MFSCLs show an increase in positive power towards the centre of the CL. The report indicated that the lens is highly pupil-size dependent. Individual responses with the lenses can vary due to different pupil size, age, lighting, near work expectations and environmental conditions. A pupil size of at least 3 mm is required so that a person can view through the distance power for the low addition range of the lenses and a pupil size of 3.6 mm is required to enter the distance power when the add selection is increased to medium and high-power additions (Figure 12). Therefore, the report (Montés-Micó et al., 2014) concluded that the power of the MFSCLs can vary among different people of the same age, and the outcome of the visual quality using the same lenses can also vary among different persons.

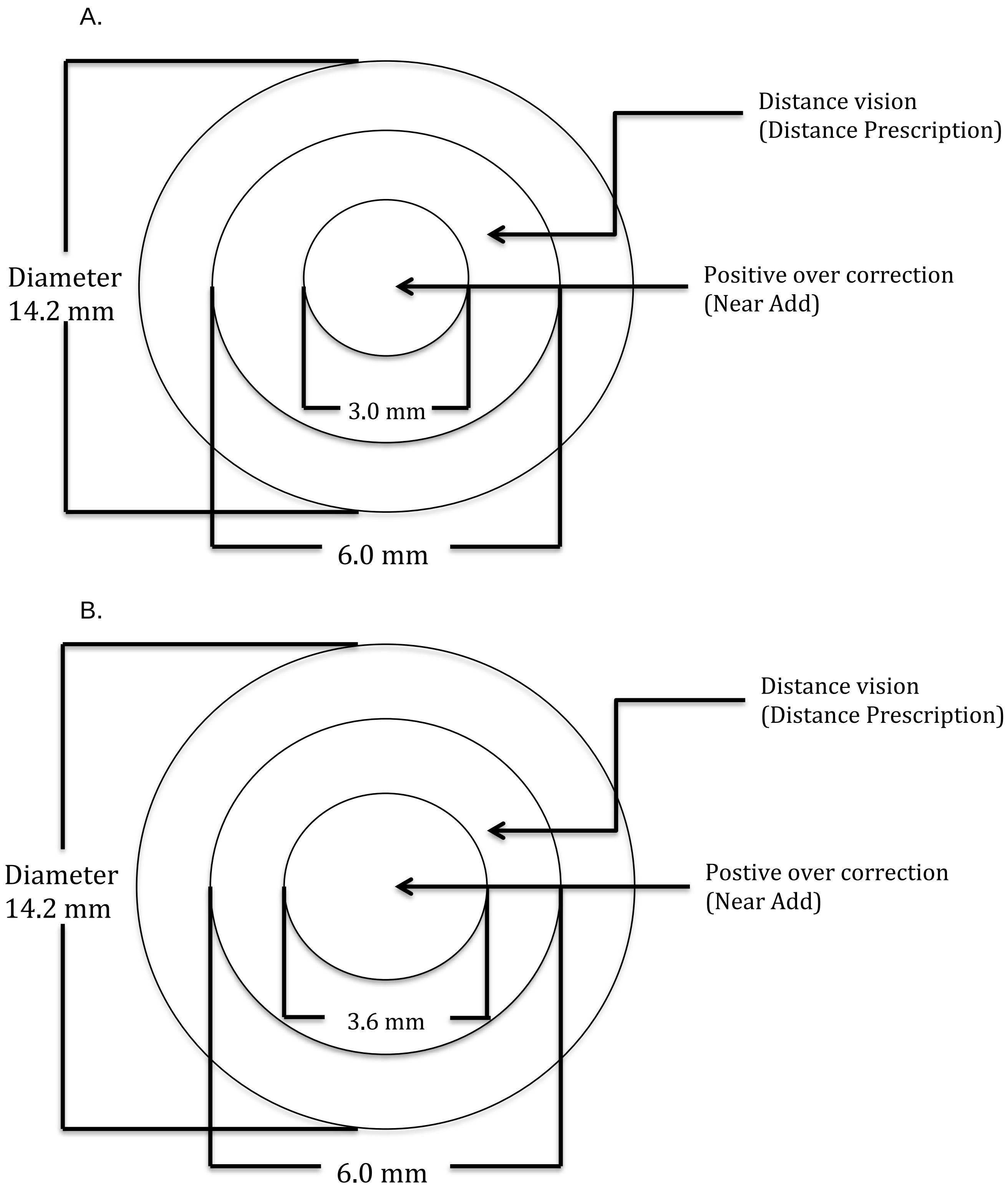


Figure 12: Schematic drawing of Air Optix Aqua multifocal showing areas of near addition power and distance power. (A: Air Optix Aqua Multifocal Low Add; B: Air Optix Aqua Multifocal Medium and High Add).

2.6.3 Simultaneous Imaging MFSCLs and Vision

Simultaneous imaging MFSCLs resulted in having light rays from both near and far targets being imaged simultaneously on the retina. This process requires the brain's ability to select between the far and near images (Llorente-Guillemot et al., 2012; Madrid-Costa et al., 2013). Previous studies (Gupta et al., 2009; Llorente-Guillemot et al., 2012; Madrid-Costa et al., 2013; Rajagopalan et al., 2006) indicated that simultaneous MFSCLs provide good binocular VA and performs well in photopic conditions, with some reduction in the contrast sensitivity function (CSF) in mesopic conditions. Because CSF tests the sensitivity of the detection function of an eye on objects of various contrast, it is used to determine the visual performance of an individual's eyes. However, these studies were only conducted on presbyopic subjects and most of the tests were performed within a clinical setting and did not take into consideration the subject's daily activities.

Recently, Fedtke and coworkers (2016b) conducted a study to assess the visual performance of single vision and MFSCLs on non-presbyopic myopic eyes. It was reported that a decrease in the HCVA was observed when comparing between the single vision control lenses to all the MFSCLs used in the study. Some MFSCLs show clinically minor differences in the HCVA, with Air Optix multifocal low add providing the best HCVA among all the test MFSCLs. However, even though there was a decrease in the HCVA, it was noted that overall, participants were still able to have -0.05 and 0.03 LogMAR vision with Air Optix low and high add lenses, respectively, indicating that vision can still reach close to 0.00 LogMAR, which can be considered as relatively safe and clear.

Although visual performance testing provides information on MFSCLs affecting the vision in young adults as compared to single vision lenses. It was proposed (Fedtke et al., 2016b; Papas et al., 2009) that the subjective vision performance results were more useful in understanding the performance and acceptance of these types of lenses. In the same study (Fedtke et al., 2016b), performance responses were also collected from the participants and all multifocal test lenses were rated significantly worse in visual performance compared to the single vision control lens, except for the Air Optix low add and PureVision low add lenses, where no significant difference was found. Since there was no adaptation period given to the participants in their study while wearing the MFSCLs, the authors proposed that visual and subjective performance might improve if given a longer adaptation period based on the finding by Fernandes et al. (2013), showing improvement in HCVA after 15 days of wearing MFSCLs among their participants.

2.6.4 Visual Treatment with MFSCLs

Asthenopia at near distances can be experienced by pre-presbyopic individuals due to different ocular conditions. Most of the conditions caused blurred near vision and eventually lead to symptoms of headache and ocular fatigue.

Pettersson et al. (2011) quoted that about 5% of young children and adults having good distance VA and without any ocular disease, have reduced accommodation ability, which resulted in blurred vision at near distances, therefore leading to asthenopia after an extended period of near viewing. The report also suggested that pseudomyopia, which is a reversible type of myopia, might be present in individuals who have spasms of the ciliary muscle after performing prolonged near tasks. These spasms can be constant or intermittent and can lead to blurred vision at near. Treatment such as prescribing near plus addition to reduce the blurred vision can be incorporated.

Binocular vision dysfunction can also lead to asthenopia in pre-presbyopic individuals with a high amount of convergence and high AC/A ratio. To maintain clear single binocular vision at near distances, the accommodation response to the accommodation stimulus at near is reduced: this may be similar to the above mentioned accommodative condition. A high amount of convergence can also be a secondary condition from accommodation, i.e. accommodative excess causing convergence excess resulting in ocular asthenopia after performing long hours of near tasks. The treatment of choice is also by prescribing plus addition to reduce the blurred vision at near distances and thereby, relaxing the accommodation and reducing the amount of convergence (Libassi et al., 1985; Pettersson et al., 2011).

In pre-presbyopic individuals who have reduced accommodative ability, pseudomyopia or convergence issues with high AC/A ratio, ophthalmic lenses with near addition can be prescribed to improve their symptoms with prolonged near tasks (Scheiman and Wick, 2014). Alternatively, MFSCLs have been suggested as a treatment option (Chu and Huang, 2010; Edmondson, 1985).

MFSCLs are designed to provide a clear foveal image when a presbyopic individual is conducting near tasks. Therefore, it has been suggested that MFSCLs can also be a possible correcting option to relieve the accommodation and binocular dysfunction condition in pre-presbyopic subjects (Chu and Huang, 2010; Edmondson, 1985; Libassi et al., 1985; Madrid-Costa et al., 2011; Pettersson et al., 2011). However, the capability of MFSCLs as a successful treatment option for accommodation and binocular vision conditions is not fully understood, because there has been no study conducted; therefore, the effectiveness of using these lenses for treatment is inconclusive.

Although multiple studies (Barodawala and Dave, 2014; Gong et al., 2017; Kang et al., 2015; Kang and Wildsoet, 2016; Lee et al., 2015; Libassi et al., 1985; Madrid-Costa et al., 2011; Pettersson et al., 2011; Tarrant et al., 2008) have been performed to observe the effect of MFSCLs on accommodation and other visual conditions in pre-presbyopic individuals, few studies have examined the effectiveness of MFSCLs in alleviating asthenopic symptoms.

González-Méijome and colleagues (2011) conducted a study using centre-distance low add MFSCLs (Proclear EP) on pre-presbyopes and early presbyopes to determine whether the CL was able to relieve asthenopic symptoms. Forty-one participants were randomly assigned to either single vision or MFSCLs treatment group. Each participant wore the lenses and returned for a follow-up visit after one week and one month of lens wear. It was found that MFSCLs with low addition were able to significantly improve the end-of-day asthenopic and visual discomfort conditions in their participants when compared to single vision CLs, with an improvement in asthenopic symptom by 8.33% versus 5%, respectively. However, the study participants in both the treatment and placebo groups comprised of both pre-presbyopes and early presbyopes; this might affect the result observed in the study because the near addition in the MFSCLs might have ameliorated the blurred vision experienced by the early presbyopes, resulting in an improvement in the asthenopic symptoms' score.

Hua and coworkers (2012) reported in their case study that centre-near MFSCLs do improve the visual symptoms of some of their patients with mild traumatic brain injury (TBI). The study was based on a series of controlled, cross-over studies conducted among five TBI patients with asthenopic symptoms, who were randomly fitted with either SVCLs or MFSCLs with centre-near design (Proclear EP) and using a CISS questionnaire as the main outcome measure to determine visual discomfort symptoms. The main objective of the study was to examine the possibility of using CL correction to manage mild TBI patients with accommodative dysfunction and to determine whether MFSCLs were able to decrease the visual discomfort. The author reported that only two of the patients had subjective improvement in their visual discomfort after wearing MFSCLs, and concluded that MFSCLs should be considered as a potential option in managing visual discomfort with selected TBI patients. However, if each case was analysed carefully, it could be seen that four of the five patients had a decrease in CISS score after wearing MFSCLs when compared to baseline data, only that the score did not go below the threshold level that was considered clinically significant. Two patients, who responded that MFSCL did not ameliorate their symptoms after wearing MFSCLs, had also reported end-of-day discomfort with CLs and excessive lens movement. These reasons might have affected their CISS score. Besides that, the study only recruited five participants; therefore, further study with larger number of participants is required to determine the effectiveness of MFSCLs on asthenopic condition (Hua et al., 2012).

2.6.5 Accommodative Responses with MFSCLs

Libassi et al. (1985) reported that non-presbyopic participants responded well to the near addition portion of the bifocal soft CLs. The study's conclusion was based on the participants' near phoria changes with the bifocal CLs compared to spectacle addition and spherical CLs with near addition, and concluded that bifocal soft CLs are as effective as the latter two methods. The report concluded that it is an effective substitute for pre-presbyopic individuals who require single vision near (SVN) addition or bifocals for near tasks due to asthenopia.

Tarrant et al. (2008) used bifocal soft CLs to assess the accommodative errors of young myopic and emmetropic adults, illustrating that accommodation response was affected by the simultaneous vision CLs. In the study, a comparison between single vision distance, SVN and simultaneous vision bifocal soft CLs on accommodative response for four target distances were conducted and it was found that young myopic adults exhibit larger amounts of lag of accommodation compared to young emmetropic adults. It was also found that bifocal soft CLs with a near addition of +1.50 D caused the initial lag of accommodation to become lead of accommodation and these changes were even larger than that observed with the SVN lens, thereby indicating that young pre-presbyopic individuals respond well to the near addition of simultaneous vision CLs.

Gong et al. (2017) studied the effect of MFSCLs on young children's accommodation and phoria, suggesting that young children do relax accommodation when being fitted with MFSCLs. In the study, the children, aged between 7–15 years, were fitted with both SVCLs and centre-distance MFSCLs with an addition power of +2.50 D and the CLs were given a settling time of 10 min before the data were collected. The study reported that the lag of accommodation in children wearing MFSCLs was slightly larger than when wearing SVCLs. The author explained that the accommodative response reduction observed might be due to the utilisation of the positive addition of the MFSCL, which relaxes the accommodation, and/or the positive SA induced by the MFSCLs, which together with the ocular SA created a larger depth-of-focus within the visual system, thereby providing a larger range of clear vision, which indirectly reduced the need for the children to accommodate. The children in the study also exhibited an increase in the near exophoria, which the author explained agrees with the conclusion that accommodation was indeed relaxed by the MFSCLs.

Kang and Wildsoet study (2016) on young pre-presbyopic adults using Proclear™ aspheric centre-distance MFSCLs with an addition of a +1.50 D and +3.00 D, shows that there was an increase in the lag of accommodation immediately upon wearing the MFSCLs, but the increment was not found after two weeks of wearing the lenses. In the study, similar to Gong and colleagues' work (2017), an increase in near exophoria was observed in all the participants for both MFSCLs' addition and this change remained after two weeks of wearing the lenses. It was suggested by the author that since positive lenses are expected to create a shift in exophoric direction, a change in the phoria could therefore be used as a surrogate indicating possible changes to the accommodation induced by the MFSCLs.

However, other studies reported that MFSCLs do not cause any change in the accommodation in pre-presbyopic subjects.

Pettersson et al. (2011) studied the effect of MFSCLs on the accommodation response in 20 young pre-presbyopic subjects aged from 21–35 years. In the study, the subjects were fitted with Proclear™ aspheric MFSCLs with an addition of a +1.00 D centre-distance design. After four hours of adaptation, the lag of accommodation was measured, and VA was checked monocularly and binocularly. The study concluded that pre-presbyopic individuals wearing MFSCLs with +1.00 D addition do not relax their accommodation and therefore will not be an effective treatment option if the treatment purpose is to reduce accommodation effort or to reduce blurred vision at near distances.

Madrid-Costa et al. (2011) also indicated that MFSCLs did not cause any changes to the accommodation response for pre-presbyopic adults. Their study aimed to determine whether MFSCLs could reduce the accommodative response of normal young adults since the lens was supposed to provide clear near images when viewing near objects. Ten young participants were recruited in the study and randomly fitted with three different aspheric centre-near design MFSCLs (Pure Vision Low Add, Pure Vision High Add and Focus Progressive). After lens insertion, the accommodative and pupil responses of the participants for accommodative stimuli of 2.50 D and 4.00 D were recorded. Results were compared to the results of SVCLs obtained using the same accommodative stimuli mentioned above. The study concluded that the MFSCLs do not provide clear enough images of near objects to create any significant change to the response of accommodation in young subjects and therefore, will not be effective as an option to reduce the accommodation response. However, it was indicated that the power of the study was relatively low; therefore, the result of the report should be taken with caution (Madrid-Costa et al., 2011). It was also indicated that there was no adaptation period given to the participants wearing the MFSCLs and the author suggested that if a longer period of adaptation time was provided, a different result may be obtained as previously reported by Montés-Mićo and Alió (2003) who noted that individuals with simultaneous focus multifocal implants required a learning process of many months for the intra-ocular lenses to reach maximum clarity.

Barodawala and Dave (2014) studied the accommodative lag in young myopic adults using centre-near low addition MFSCLs, and showed that the lag of accommodation increased after wearing MFSCLs. No clear conclusion was proposed by the author on the reason for the increase in the lag of accommodation observed after wearing the MFSCLs. Additionally, there was no indication on whether any adaptation period was given to the participants wearing the MFSCLs.

Lee et al. (2015) compared the accommodative function of young adults wearing three different types of CLs conditions: monovision, modified monovision and aspheric centre-near low addition MFSCLs. All participants were given an adaptation period of one week with each lens type and accommodative function was assessed only after exposing the participants to 1 hour of near visual tasks. It was found that the monovision lenses resulted in a reduction of the accommodative response compared to the modified monovision and MFSCLs. However, when comparing the lag of accommodative responses of the MFSCLs to the SVCLs during the 2.50 D stimulus, the amount of accommodative response was very similar, even though the MFSCLs were reported to have slightly better accommodative response compared to the SVCLs [1.08 (SD = 0.39) vs 0.92 (SD = 0.34)]. Due to statistically insignificant results, the author concluded that the lag of accommodation between the two lenses was similar and that the MFSCLs in the study did not relax the accommodation. In the study, the NRA and PRA were also assessed with single vision and multifocal CLs. It was found that the NRA value was slightly lower for the MFSCLs; this might be due to the additional power in the CL. However, the NRA difference between the two CLs was also not statistically significant.

The variation in results from the different studies might be due to some of the following factors.

In Libassi and colleagues' (1985) and Tarrant's (2008) studies, bifocal soft CL was used. The former study used Ciba Vision BI-SOFT, which is a conventional anterior surface, bi-curved, concentric centre-distance bifocal design. The additional power of the lens in the study was +1.50 D. However, due to the concentric design, the near add zone may be more distinct compared to the aspheric simultaneous designed MFSCLs. A change in the value of near phoria of the participants was used as an indication of whether accommodation was affected by the near addition, which is different compared to the other two studies (Gong et al., 2017; Kang and Wildsoet, 2016). The latter study uses a 2-mm centre-distance bifocal and five alternating zones of near and far distances. Due to the discontinuation of the zone of the lens design, it was impossible for the refractometer to provide a valid reading. Therefore, subjects were tested with a bifocal CL in one eye while viewing the target and the other eye wore a single vision distance lens to obtain the reading; this was based on the concept of consensual responses, where the near addition of the eye wearing the bifocal CL will affect the fellow eye and causes relaxation to the accommodation. Therefore, the conclusions of the studies were drawn by using different outcome indicators, which can lead to varying conclusions regarding the effect of near addition on the eye compared to other studies.

In the Pettersson et al. (2011) study, the centre-distance MFSCLs was also used but it was an aspheric simultaneous design. In the study, no significant differences in the lag of accommodation were observed, which may have been due to the near addition power being too far away from the centre of the lens. The progression to the full addition zone in the lens may start to progress from a radius of 2.5 mm from the centre of the lens to a radius of 4.25 mm, which will require a pupil size of 6 to 7 mm to view through the full +1.00D add zone and can be very difficult because the pupil will be constricted when viewing up-close objects. Therefore, in the study, subjects might not be focusing through the reading portion of the MFSCL, resulting in no effect with the near addition to the accommodation of the young subject.

Kang and Wildsoet (2016) used the same design of MFSCL as Pettersson et al. (2011), but with a higher addition of +1.50 D and +3.00 D. The higher additional power may result in more additional power being provided to the participant in the study. Gong et al. (2017) used a similar centre-distance MFSCL with a slightly larger centre distance zone of 3 mm and additional power of +2.50 D. Both studies (Gong et al., 2017; Kang and Wildsoet, 2016) concluded that pre-presbyopic individuals' accommodation responded to the additional power of the lens due to the significant exophoric shift found. The inconsistent conclusions drawn from these studies may be due to the different near addition powers used, even though the lens design was similar. Also, Pettersson's study did not include heterophoria findings of their participants while wearing the MFSCLs; this may also explain why the conclusions between the studies were inconsistent.

Madrid-Costa et al. (2011), however, used an aspheric centre-near design of MFSCL. As indicated in the report, there was no adaptation time for the subjects in the study while wearing the lenses; therefore, the additional power in the MFSCL might not have affected the subjects' accommodation. Barodawala and Dave (2014) also did not indicate any adaptation period for the participants wearing the MFSCLs, but their finding was different from Madrid-Costa. As the adaptation times given to the participants in these studies (Barodawala and Dave, 2014; Madrid-Costa et al., 2011; Pettersson et al., 2011) were no longer than one day before the results were obtained, it might have resulted in a false negative finding. On the contrary, Lee et al. (2015), who used the centre-near MFSCLs, allowed their participants to wear the CLs for one week and their results showed that MFSCLs have slightly better accommodative response than single vision lenses, but it was not statistically significant; this finding might indicate that a longer adaptation period may improve the accommodative responses because there is a possibility that a learning effect may occur after prolonged exposure to simultaneous vision lenses (Montés-Mićo and Alió, 2003).

Therefore, all the above-mentioned studies either used a different lens design or that there was no significant adaptation period given, thereby resulting in variation in the conclusion regarding the effects MFSCLs had on accommodation. Also, no study has been conducted to determine the effect of MFSCLs as an alternative treatment option for ocular asthenopia. However, MFSCLs have been discussed as an option for optometrists to prescribe for patients with near vision disorders in non-presbyopic individuals that require near add lenses (Chu and Huang, 2010; Edmondson, 1985).

2.7 Convergence Insufficiency Symptoms Survey (CISS) Form

The CISS form (Appendix 4) is an optometric questionnaire designed to determine the presence of symptoms of convergence insufficiency. This form has been validated by Rouse et al. (2004), and the report indicated that CISS form shown good validity and reliability when used for evaluating symptoms in adults 19 to 30 years. The authors also stated that a CISS score of 21 or higher could be used to distinguish between normal and abnormal symptoms in adults (Rouse et al., 2004).

Even though the CISS form was designed for convergence insufficiency symptoms, the form contains information that most optometrists will ask about near discomfort (García-Muñoz et al., 2014; Lambooij et al., 2010). Scheiman and Wick (2014) have also indicated that CISS form can be used in clinical practice to compare symptoms before and after optometric intervention for other binocular vision and accommodative disorder. Therefore, CISS form can be used as a primary outcome indicator for detecting visual fatigue symptoms in individuals in this study.

2.8 Zeiss i-Profiler^{Plus}

The Zeiss i-Profiler^{Plus} (Figure 13) is a type of wavefront aberrometer autorefractor. It can perform ocular wavefront aberration measurements, thereby providing information on both the low- and high-order aberrations of the eyes using the Hartmann-Shack microlens array sensor (Zeiss, n.d; Lebow and Campbell, 2014).

The Zeiss i-Profiler^{Plus} can measure refractive errors up to spherical power values between ± 20 D for a pupil size of 3.5 mm and ±15 D for a 5.5-mm pupil size. The cylindrical power autorefraction measurement range is calibrated to be between 0 to 8 D and axes from 0^0 to 180^0. Three measurements of the refraction reading are usually taken during the measurement process and the median values are selected. No averaging of the data is available (Zeiss, n.d; Lebow and Campbell, 2014).

The corneal topography component of this machine contains a total of 22 rings with 18 complete rings and measures up to 3,425 points on the cornea. It has an accuracy of ± 0.05 (SD = 0.01mm) and a reproducibility of ± 0.10 D (SD = 0.02 mm) (Zeiss, n.d).

Lebow and Campbell (2014) compared the accuracy of the refraction using traditional and wavefront autorefractors, and reported that the Zeiss i-Profiler^{Plus} spherical equivalent refractive result was slightly more minus compared to the subjective refraction by about -0.11 D. The cylindrical power result compared to the subjective refraction differed by only 0.05 D. Both the spherical equivalent and cylindrical result differences were below the significant level of 0.25 D set in the study and therefore showed that the Zeiss i-Profiler^{Plus} is reliable in clinical settings for testing the refractive status

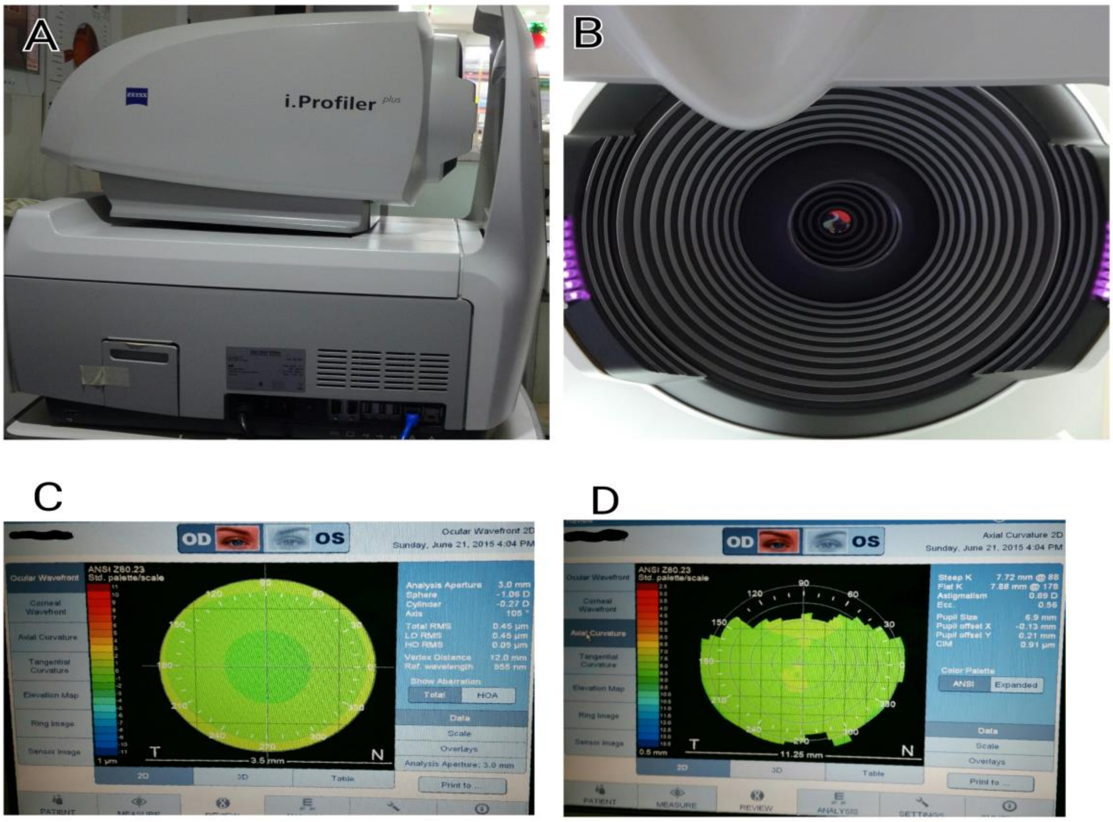


Figure 13: Zeiss i-Profiler^{Plus} for objective refractive measurement and corneal topography. A) i-Profiler® Plus side view. B) Topography ring with centre fixation close field auto-refraction target. C) Objective refraction result. D) Topography result with steep and flat K reading.

2.9 Summary

There is an understanding that larger accommodative lag could be more commonly seen in myopes than emmetropes (Gwiazda et al., 1993; Gwiazda et al., 2004; Gwiazda et al., 2005; Koomson et al., 2015; Koomson et al., 2016) and the presence of lag of accommodation with prolonged near tasks (Chase et al., 2009; Tosha et al., 2009) might result in asthenopia. Therefore, reducing the accommodative error at near distances may relieve the asthenopic symptoms. Previous studies have shown that lowering of the myopic prescription was effective in reducing the amount of accommodative lag (Bao et al., 2013; Gwiazda et al., 2004; Koomson et al., 2015; Koomson et al., 2016; Rosenfield and Carrel, 2001). Currently, ophthalmic lenses and soft CLs with near addition are both available. However, companies (Essilor Visual Fatigue Solution, n.d; Zeiss Digital Lenses, n.d) have marketed only ophthalmic lenses as an effective option to reduce asthenopic symptoms (Lee, 2011; Larrard et al., 2015; Meister, 2016). Although there have been reports (Chu and Huang, 2010; Edmondson, 1985) indicating the use of MFSCLS as a treatment option for accommodation and binocular vision treatment, manufacturers do not corroborate the effectiveness of such use.

Because CLs are commonly prescribed in Singapore (Teo et al., 2011), this intrigued me to investigate whether MFSCLs can alleviate the asthenopic symptoms in myopic CL wearers with lag of accommodation. An exhaustive literature review indicated that only two studies (González-Méijome et al., 2011; Hua et al., 2012) have been conducted to determine the effectiveness of MFSCLs with asthenopic symptoms. However, González-Méijome and co-workers' study consists of early presbyopes, who may have affected the conclusion of the report. Hua and colleagues' study participants were mainly TBI patients, and therefore the result might not apply to ordinary myopes.

The assessment of the accommodative response of pre-presbyopes to the near addition power of MFSCLs is also an important aspect. Multiple studies

(Barodawala and Dave, 2014; Gong et al., 2017; Lee et al., 2015; Libassi et al., 1985; Madrid-Costa et al., 2011; Pettersson et al., 2011; Tarrant et al., 2008) had been conducted to observe the accommodative response of pre-presbyopes wearing MFSCLs using objective measurement, with inconsistent conclusions. However, no study has investigated the accommodative response with MFSCLs using common clinical methods, and the effect MFSCLs have on the accommodative response after one month of wear: this vital information could provide valuable insights and aids in the decision-making in real-world optometric clinical practice. Currently, there is also a lack of information on the diagnosis and management of asthenopic patients by Singapore optometrists and their opinion on the use of MFSCLs for relieving asthenopic symptoms.

Hence, the research presented in this thesis aimed to:

- Examine the effectiveness of MFSCLs in alleviating asthenopic symptoms in myopes with lag of accommodation.
- Examine the effect of MFSCLs' near addition power on the accommodative response of pre-presbyopic myopes immediately and after one-month wear.
- Describe the diagnosis and management of asthenopic conditions by Singapore optometrists and the understanding of their concern on the use of MFSCLs as a treatment option for asthenopic patients.

3.0 Efficacy of Multifocal Soft Contact Lens on Asthenopic Orthophoric and Esophoric Myopes with Lag of Accommodation

3.1 Introduction

Asthenopia may be due to multiple conditions (Sheedy et al., 2003). As discussed in Section 2.5, prolonged usage of the eyes for near tasks has been a concern as a source for inducing visual fatigue. These symptoms for visual discomfort may be experienced immediately or may accumulate over time and surfaced at a later stage (Murata et al., 1996).

Another possible contributing factor to the symptoms of asthenopia may be lag of accommodation. As discussed in section 2.2, lag of accommodation is an error in the accommodative response whereby the amount of accommodation response is lesser than the accommodative demand (Gross et al., 2012; He et al., 2005; Rouse et al., 1982; Scheiman and Wick, 2014), creating a constant slight blurring of the near tasks as the focusing is never on the object observed. The average amount of lag of accommodation commonly detected clinically range about +0.50 D (SD 0.25). Also, myopes tend to present with a higher amount of lag of accommodation as compared to emmetropes (Gwiazda et al., 1993; Gwiazda et al., 2004; Gwiazda et al., 2005; Koomson et al., 2015; Koomson et al., 2016; McBrien and Millodot, 1986; Nakatsuka et al., 2005). However, this slight blurring of vision is usually unnoticed, and it may or may not affect reading ability (Chung et al, 2007; Sohrab-Jam, 1976).

Lag of accommodation has also been found to be higher in asthenopic symptomatic individuals when compared to those with lesser symptoms (Chase et al., 2009). Indeed, a strong correlation exists between symptoms of asthenopia and lag of accommodation, whereby symptoms of asthenopia increase with the degree of accommodative lag. A study by Tosha et al. (2009) also observed that lag of accommodation increased in the higher discomfort group while such accommodative lag remained the same in the lower discomfort group after a period of near tasks, indicating that lag of accommodation was related to ocular fatigue symptoms.

Long hours of near visual task and the presence of lag of accommodation may therefore increase the probability of asthenopic symptoms, in particular with the high-intensity usage of digital devices. With the invention of smart phones, tablets and computers, people are spending more time undertaking near work (Digitalinfluencelabcom, 2015; Tnsglobalcom, 2015), with the working distance and font size of such devices being greatly reduced (Bababekova et al., 2011; Long et al., 2017). A reduction in working distance can cause an increase in the amount of lag of accommodation (Charman, 1999) and adds more stress on the vergence and accommodation systems.

One common method to reduce fatigue is to use plus power correction during near tasks. Studies (Bao et al., 2013; Gwiazda et al., 2004; Koomson et al., 2015; Koomson et al., 2016; Rosenfield and Carrel, 2011) have shown that by using this approach, it can reduce the amount of accommodative lag, which improves the focusing ability of individuals at near distance, and reduces the amount of vergence and accommodation effort at the same time. Some commercial ophthalmic companies such as Essilor (Essilor Visual Fatigue Solution, n.d; Larrard, 2015; Lee, 2011) and Zeiss (Meister, 2016; Zeiss Digital Lenses, n.d) have introduced enhanced single vision lenses (ESVLs) that incorporate near addition power at the lower portion of the distance prescription lens to reduce visual strain at near distance for pre-presbyopes. However, no detailed study has been conducted on the use of MFSCLs for reducing visual strain at near distance with a pre-presbyopic population.

MFSCLs were designed to incorporate a near addition prescription in the contact lens (CL) to provide clearer vision for presbyopes. Suggestions that MFSCLs could also be used as a possible correcting option to reduce the accommodation and binocular dysfunction of pre-presbyopes have been studied (Gong et al., 2017; Kang et al., 2015; Kang and Wildsoet, 2016; Libassi et al., 1985; Madrid-Costa et al., 2011; Pettersson et al., 2011). However, the ability of MFSCLs as a successful treatment option for ocular asthenopia varies, and is not entirely understood (González-Meijome et al., 2011; Hua et al., 2012). Although no strong evidence is available, MFSCLs have been suggested as a favourable option for optometrists to prescribe for non-presbyopes with near vision disorder that require near add (Chu and Huang, 2010; Edmondson, 1985).

Due to the lack of literature to date on the effects of MFSCLs on asthenopic myopes with lag of accommodation, it would be valuable to determine whether MFSCLs are able to reduce asthenopic symptoms in symptomatic, orthophoric and esophoric myopes with lag of accommodation by using clinical methods that are commonly conducted in general optometric practice. The study will also assess whether the amount of MFSCLs' addition will differentially modify symptoms of asthenopic individuals.

The hypothesis is that MFSCLs with centre-near design may reduce the asthenopic symptoms among the symptomatic orthophoric or esophoric myopes with a lag of accommodation.

3.2 Methods, Material and Clinical Procedures

3.2.1 Methods

A double blind, cross-over study (Figure 14) was conducted at Ong's Optics, a private optometric practice in Singapore, following approval from the Aston University Research Ethics Committee (AU REC). The study adhered to the tenets of the Declaration of Helsinki and all participants gave their informed consent to participate in the study after the objective of the study, methods, benefits, potential risks of taking part and their right to exit the programme at any point in time after participating in this study were explained.

A sample of 24 participants, 9 males and 15 females, with age range from 18−35 years were recruited. Participants were recruited from the general public and patients within the practice where the research was conducted. Recruited participants were all existing contact lens wearers. Inclusion criteria were age 18−35 years, myopia with spherical equivalent of more than or equal to -0.75 D, astigmatism not more than -1.00 Dc, presence of near orthophoria or esophoria and lag of accommodation ≥ +0.75 D, presence of asthenopic symptoms based on a Convergence Insufficiency Symptom Survey (CISS) form (Appendix 4) score ≥ 21, best corrected visual acuity (VA) of logMAR 0.10 or better in each eye at distant and near. Exclusion criteria included any ocular disease, amblyopia and/or strabismus, any form of ocular surgery or injury. All participants were given an eye examination, which included objective and subjective refraction, Monocular Estimate Method (MEM) retinoscopy, slit lamp biomicroscopy, fundus examination, distant and near phoria, amplitude of accommodation, contrast sensitivity, and symptoms survey using the CISS form.

Once recruited, each participant was required to wear three different types of CLs each month for three months and return for four follow-up visits. Before fitting the participant with any CLs, corneal topography and objective refraction reading were obtained using the Zeiss i-profiler^{Plus}. Details of the instrument can be found in Section 2.8.

All participants were fitted with single vision contact lenses (SVCLs) during the first visit, so that baseline data regarding the accommodative lag, heterophoria and symptom score can be established. After checking the lens fit on the eyes, distance and near VA were evaluated. If either distance or near VA were not corrected to at least logMAR 0.10, over refraction was conducted and the CLs were replaced with the new prescription. Once the actual prescription for the CLs was confirmed, MEM retinoscopy was carried out to determine the amount of accommodative lag.

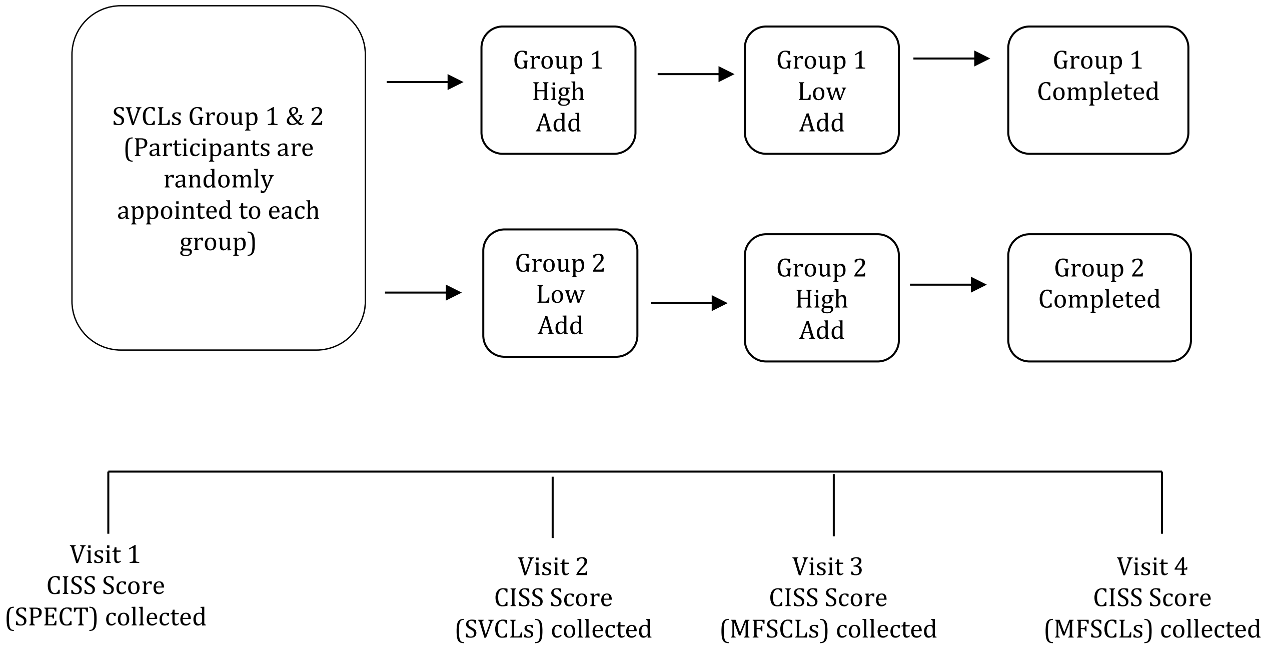


Figure 14. Schematic representation of study cross-over design. Participants were randomly appointed to each group during the 1st visit and return for a total of 3 visits after each month. CISS symptoms score was collected from individual participant during each visit after wearing the test lenses for 1 month.

Participants were instructed to wear the CLs for at least five days a week and eight hours a day for one month. When participants returned for their follow-up visit, MEM retinoscopy was again performed with the CLs in situ. Participants were also given the CISS forms for grading their symptoms of fatigue after wearing the CLs.

During the second visit, participants were randomly fitted with either MFSCLs low add or high add. The randomising process was conducted by an optometrist colleague, who would randomly allocate the MFSCLs addition to the participants. The detail of the MFSCLs fitted to the participant was recorded, and the colleague throughout the entire study kept this form. The procedure for lens fit, VA evaluation and MEM retinoscopy were repeated in similar sequence as the first visit and participants were instructed to wear the CLs with the same schedule as the SVCLs for one month.

During the third visit, the same procedures were repeated with the participants swapping to the other multifocal addition. The entire process of recruiting and randomisation is illustrated in Figure 14.

All clinical findings were obtained by the same optometrist, who was masked to the randomising of the MFSCLs that were issued to participants.

3.2.2 Contact Lenses

Participants were first fitted with Air Optix Aqua sphere (Alcon Laboratories, Fort Worth, US) CLs during the first visit, and were randomly fitted with two different simultaneous vision MFSCLs during the second and third visit. The two MFSCLs chosen for this study were Air Optix Aqua Multifocal Low Add (Alcon Laboratories, Fort Worth, US) and Air Optix Multifocal Aqua High Add (Alcon Laboratories, Fort Worth, US). Both Air Optix Aqua sphere and multifocal lenses have a base curve of 8.6 and 14.2 mm of total lens diameter. The lens is manufactured from lotrafilcon B material that has a water content of 33%. The only difference is that the Air Optix Aqua sphere is a single vision lens, whereas the Air Optix Aqua multifocal lens is a simultaneous image centre-near design lens with double aspheric surface. There are three near addition available but in this research only the low add (maximum add +1.00D) and the high add (maximum add +2.50 D) were used. Near and intermediate power is designed to be in the portion of the optic zone while the distance power is in the portion surrounding it. Detail of the multifocal lens design can be found in Section 2.6.2 (Figure 12). Each participant was instructed to wear each type of CL for a month, at least five days a week and eight hours per day.

3.2.3 Subjective Refraction

Subjective refraction was conducted using the trial frame and trial lenses. Participants' both eyes were initially subjectively refracted monocularly with maximum plus power consistent with the best VA. Participants were then binocularly balanced using the Humpriss Balancing method (Rosenfield, 2009a); this was to ensure that a maximum plus sphere result was obtained for each participant.

3.2.4 Pupil Size Measurement

Pupil size was measured using a pupil distance (PD) ruler. Participants were instructed to view the target, one to two lines above the best VA of the uncorrected conditions at a distance of 6 m. Photopic pupil size was measured with the room light on (about 400 lux), while mesopic pupil size was measured with the room light off and having only a very dim diffuse light from a pen-light, placed close to the eyes temporally. The PD ruler was placed as close as possible to the pupil inferiorly, and the measurement was taken to the nearest 0.5 mm. Pupil size of participants while viewing near task was not measured.

3.2.5 Monocular Estimate Method (MEM) Retinoscopy

The amount of lag of accommodation was measured using MEM retinoscopy. Participants wearing the full distance spectacle prescription or the CLs was asked to focus on the near target on the fixation ruler with letter size of N5 at a distance of 40 cm and was instructed to keep the letter clear at all times. The test was conducted with normal room light (about 400 lux) so that participants could see the near target clearly and to provide a close-to-normal environment for near task viewing. Retinoscopy light was swept across the eye along the horizontal meridian, and the movement of the light was observed. A lens to neutralise the movement was briefly introduced in front of the eye using trial lenses. When testing with the CLs, participants wore the trial frame so that the neutralisation lens was consistently placed at the same testing distance in front of the eye, which was at a vertex distance of 12 mm; this procedure was repeated until the retinoscopy light reflex was neutralised or reversed. The lens that neutralised or reversed the reflex was then recorded.

3.2.6 Heterophoria Measurement

Distant phoria was measured using the Von Graefe method (Evans, 2009; Scheiman and Wick, 2014). With participants wearing their full distance prescription and viewing a 6/7.5 letter at 6 m, a 6 prism (Δ) base-down was introduced before the right eye (RE) and a 12Δ base-in before the left eye (LE). The reason for the vertical and horizontal prism induced was to create an obvious diplopia for the participants. The vertical prism will create vertical diplopia, and the horizontal prism will produce horizontal diplopia. As there is no fusion, the 12Δ base-in will not result in any form of adaptation to the eyes (Scheiman and Wick, 2014). The amount of prism selected to create diplopia in this procedure was based on the standard textbook recommendation (Scheiman and Wick, 2014). Participants were instructed to fixate at the lower target and keeping it clear while the prism on the LE was slowly reduced to bring the top image closer to the lower target. Participants were required to report once the two letters were aligned above one another. The prism amount was recorded as the distance horizontal heterophoria finding (Evans, 2009; Scheiman and Wick, 2014).

Near phoria was measured using the Maddox Wing instrument (Pointer, 2005). The Maddox wing is a hand-held device that is used to measure the amount of near heterophoria at a distance of 33 cm using the principle of dissociation of fusion by dissimilar object. Details of the instrument were described in Section 2.4.2. Participants wear the trial frame adjusted to the participant's far PD with full distance refractive prescription in place while viewing through the two eyepieces. A septum separates the view, with the RE seeing the white arrow pointing vertically upwards while the LE will see a scale in white print horizontally above the arrow, that is calibrated in diopter of deviation (1Δ = 3.3 mm at 33cm). If there is no misalignment of the ocular muscle at near, the white arrow will point at zero on the number scale. If horizontal heterophoria is present, the arrow will shift towards the right for esophoric condition and to the left for exophoric. The number reported was recorded as the near heterophoria finding (Pointer, 2005).

3.3 Statistical Methods

The research study required minimum recruitment of 18 either near orthophoric or esophoric myopic participants with lag of accommodation and symptoms of asthenopia from the general public and patients within the practice. This number of participants was derived using the G*Power 3.1.3 software (Franz Faul, Universität Kiel, Germany). The test method selected was the F test under the Test Family function and using analysis of variance (ANOVA); Repeated measures. Assuming an effect size (f) value of 0.40, an alpha error probability of 0.05, and power as 0.80, the number of groups to be 1 and the number of measurements of 3, with correlation among repeated measures of 0.5 and nonsphericity correction of 1, the total sample size recommended is 12. However, the number was pushed to 18 to increase the power to 0.95 and to allow for attrition.

IBM SPSS statistics 23 (IBM corporation, Armonk, New York) was used for statistical analysis. Microsoft Excel 2016 (Microsoft Corporation, Redmond, Washington) was used for data storage. The analysis of the data collected in this study was conducted as follows:

3.3.1 Age and Age-Gender Match

The mean function was used to analyse the age of the participants as a whole and within each group in this study. Information such as the minimum (min), maximum (max) and median age was generated using the mean function. A paired sample t-test was then conducted to determine whether there was any significant age difference between the two groups of participants. Age/gender-matched was also analysed by using the Pearson Chi-Square test to determine whether there was any relationship in the age/gender matched in each group.

3.3.2 Subjective Refraction, Pupil Size and AC/A Ratio

Subjective refraction results were also calculated using the mean function for the spherical (SPH) and spherical equivalent (SE) power (spherical power plus half of the cylinder power) data of each eye. Data were also broken down into two groups to calculate the average SPH and SE results for each group. Information such as the minimum (min), maximum (max) and range of the SPH and SE was also generated using the mean function.

The photopic and mesopic pupil size results were also calculated using the mean function for all participants, including those assigned to Groups 1 and 2. AC/A ratio was also calculated using the same mean function for spectacle, SVCLs and both low and high addition MFSCLs. Information such as the minimum (min), maximum (max) and range of the pupil diameter and AC/A ratio was also generated using the mean function.

3.3.3 CISS Score

The mean values of the CISS score for the four test conditions: spectacle (SPECT), SVCLs, low addition multifocal contact lenses (LAMFCLs) and high addition multifocal contact lenses (HAMFCLs), were analysed by using the repeated measure ANOVA to determine whether there is any significant difference between the symptoms score.

3.3.4 Lag of Accommodation and Heterophoria

The lag of accommodation of participants' right and left eyes, and the distance and near heterophoria were initially analysed using paired sample t-tests to determine whether there was any difference between pre and post wearing of all three types of CLs. Because no significant differences in the mean value were found between the pre and post wearing of each CL wore, the post-lens wearing result for each CL was used to compare against each test conditions: SPECT, SVCL, LAMFCL and HAMFCL. Comparisons of the post-lens wearing results of each condition were conducted using the repeated measures ANOVA.

3.4 Results

A total of 24 participants were recruited for this study. All participants were existing CLs wearers, and none of the participants left the study due to discomfort from CL wear. Also, no participants left the study due to unsatisfactory vision from MFSCLs wear.

Based on the mean function, the average age of participants was 22.83 years (SD 5.78). The average age of participants randomised into Group 1 and Group 2 were 22.83 years (SD 5.59) and 22.83 years (SD 6.21), respectively. Pair sample t-test shows that there was no significant difference between the age of two groups of participants; t(11)= 0, p = 1.00. A Pearson Chi-square test comparing the age/gender-matched for Group 1 and Group 2 participants was conducted. The result shows no significant relationship between age and gender for both Group 1 and Group 2; X^2 (7,N=12) = 5.33, p = 0.62 and X^2 (4,N=12) = 1.60, p = 0.81, respectively, as the p values were more than the significant value of 0.05.

Mean	**Mean**	**SD**	**N**	**Median**	**Max**	**Min**
AGE	22.83	5.78	24	20	35	18
GROUP 1	22.83	5.59	12	20	34	18
GROUP 2	22.83	6.21	12	20	35	19
Paired Samples t-Test	**Mean**	**SD**	**N**	**t**	**df**	**Sig. (2-tailed)**
GROUP 1 - GROUP 2	0.00	6.55	12	0.00	11	1.00
Pearson Chi-Square	**Value**	**df**	**Asymptotic Sig. (2-sided)**			
AGEG1*GENDERG1	5.33[a]	7	0.62			
AGEG2*GENDERG2	1.60[a]	4	0.81			

Table 2: Table showing the average age of participants in the study and the average age of participants randomised into the two groups. The table also shows the differences in the average age between the two groups using the paired sample t-test, and age/gender-matched result for each group using the Pearson Chi-Square test.

The average subjective refraction results for all participants in the study can be found in Table 3. All participants recruited do not present any form of ocular pathological condition and have best corrected VA of logMAR 0.00 monocularly at distant and near. The SE results of the subjective refraction calculated using the mean function show that the average SE of the RE and LE was -3.58 D (SD 1.76), ranging from -7.88 D to -1.00 D and -3.56 D (SD 1.54), ranging from -6.25 D to -1.13 D, respectively. In Group 1, the average SE of the RE and LE was -3.74 D (SD 2.08), ranging from -7.88 D to -1.00 D and -3.59 D (SD 1.69) ranging from -6.25 D to -1.13 D, respectively. For Group 2, the average SE of the RE and LE was -3.43 D (SD 1.45), ranging from -5.63 D to -1.13 D and -3.53 (SD 1.45), ranging from -5.63 D to -1.38 D, respectively. The minimum and maximum of the subjective refraction result of the overall participants, Group 1 and Group 2 can also be seen in Table 3.

The results of the AC/A ratio can be found in Table 4. Participants had an average AC/A ratio of 2.83 △ (SD 1.52) for SPECT, 3.46 △ (SD 1.93) for SVCLs, 3.46 △ (SD 1.77) for LAMFCLs and 3.38 △ (SD 1.74) for HAMFCLs. The expected AC/A ratio was previously reported by Scheimen and Wick (2014) to be 4:1 (SD 2). The AC/A ratio finding for SPECT and all CLs in this study was very close to the expected value.

Mean Refraction	Mean (D)	SD	N	Min (D)	Max (D)	Range (D)
RE SPH	-3.39	1.77	24	-0.75	-7.50	6.75
LE SPH	-3.34	1.50	24	-1.00	-6.00	5.00
RE SE	-3.58	1.76	24	-1.00	-7.88	6.88
LE SE	-3.56	1.54	24	-1.13	-6.25	5.13

Mean Refraction*G1	Mean (D)	SD	N	Min (D)	Max (D)	Range (D)
RE SPH	-3.56	2.09	12	-0.75	-7.50	6.75
LE SPH	-3.38	1.61	12	-1.00	-6.00	5.00
RE SE	-3.74	2.08	12	-1.00	-7.88	6.88
LE SE	-3.59	1.69	12	-1.13	-6.25	5.13

Mean Refraction*G2	Mean (D)	SD	N	Min (D)	Max (D)	Range (D)
RE SPH	-3.21	1.45	12	-1.00	-5.50	4.50
LE SPH	-3.31	1.45	12	-1.25	-5.50	4.25
RE SE	-3.43	1.45	12	-1.13	-5.63	4.50
LE SE	-3.53	1.45	12	-1.38	-5.63	4.25

Table 3: Table showing the average subjective refraction result of the RE and LE of all participants in the study. The table also shows the average subjective refraction result of the RE and LE in group 1 and group 2. (SPH indicates spherical power of the subjective refraction result and SE indicates spherical equivalent power of the subjective refraction).

AC/A Ratio	Mean (Δ)	SD	N	Min (Δ)	Max (Δ)	Range (Δ)
SPECT	2.83	1.52	24	1	7	6
SVCL	3.46	1.93	24	1	8	7
LAMFCL	3.46	1.77	24	1	8	7
HAMFCL	3.38	1.74	24	1	7	6

Table 4. Table showing the average AC/A ratio of all participants in the study for all four test conditions.

Photopic and mesopic pupil size results were also calculated. The result shows an average photopic pupil size of 3.96 mm (SD 0.57) for the RE and 4 mm (SD 0.61) for the LE. In Group 1, the average photopic pupil size of the RE and LE was 3.96 mm (SD 0.69), and 4.04 mm (SD 0.75), respectively. For Group 2, the average photopic pupil size of the RE and LE was 4 mm (SD 0.43) and 4.08 mm (SD 0.51), respectively. The mesopic pupil size was also calculated, and it was found that the RE and LE had an average mesopic pupil size of 4.97 mm (SD 0.65) and 5 mm (SD 0.60), respectively. The average mesopic pupil size of the participants RE and LE in Group 1 was 4.92 mm (SD 0.79) and 5 mm (SD 0.50), respectively, and in Group 2, 5.02 mm (SD 0.50) and 4.99 mm (SD 0.47), respectively. The results of the pupil size measurement can be found in Table 5.

CISS score analysed using ANOVA test indicated that there was a statistically significant difference between the CISS symptom results of the four test conditions, $F (1.56, 35.91) = 44.68$, $p < 0.01$, partial $n^2 = 0.66$ (Figure 15).

Mean Pupil Size (Photopic)	Mean	SD	N	Max	Min	Range
RE	3.96	0.57	24	5.00	3.00	2.00
LE	4.00	0.61	24	5.00	3.00	2.00

Mean Pupil Size (Photopic)*G1	Mean	SD	N	Max	Min	Range
RE	3.96	0.69	12	5.00	3.00	2.00
LE	4.04	0.75	12	5.00	3.00	2.00

Mean Pupil Size (Photopic)*G2	Mean	SD	N	Max	Min	Range
RE	4.00	0.43	12	5.00	3.00	2.00
LE	4.08	0.51	12	5.00	3.00	2.00

Mean Pupil Size (Mesopic)	Mean	SD	N	Max	Min	Range
RE	4.97	0.65	24	6.00	4.00	2.00
LE	5.00	0.60	24	6.00	4.00	2.00

Mean Pupil Size (Mesopic)*G1	Mean	SD	N	Max	Min	Range
RE	4.92	0.79	12	6.00	4.00	2.00
LE	5.00	0.50	12	6.00	4.00	2.00

Mean Pupil Size (Mesopic)*G2	Mean	SD	N	Max	Min	Range
RE	5.02	0.50	12	6.00	4.00	2.00
LE	4.99	0.47	12	6.00	4.00	2.00

Table 5. Table showing the average pupil size of all participants in the study in photopic and mesopic conditions. The table also shows the average photopic and mesopic pupil size of the participants in each randomized group (G1= Group 1, G2 = Group 2).

Post hoc analysis using the Bonferroni correction (Armstrong et al., 2011) comparing the CISS symptom scores between SPECT and SVCLs shows that there was no statistically significant difference between them [25.04 (SD 4.58) vs 24.46 (SD 4.59), p = 1.00]. However, significant differences were found between the CISS symptom scores of LAMFCLs compared to SPECT and SVCLs [12.17 (SD 6.89) vs 25.04 (SD 4.58) vs 24.46 (SD 4.59), respectively, p < 0.01]. When comparing the symptoms' score after wearing HAMFCLs to SPECT and SCVLs, there were also statistically significant differences between them [13.71 (SD 7.23) vs 25.04 (SD 4.58) vs 24.46 (SD 4.59), respectively, p < 0.01]. No significant difference was found when comparing the CISS symptom score between LAMFCL and HAMFCL [12.17 (SD 6.89) vs 13.71 (SD 7.23), p = 1.00].

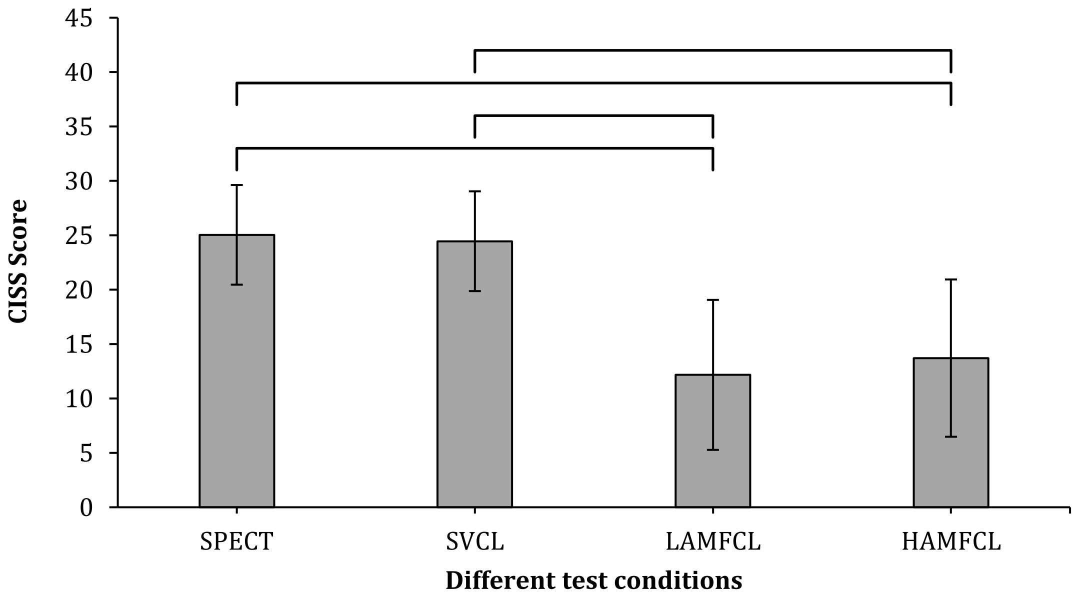


Figure 15. Bar Chart indicating participants' mean symptom scores under different test conditions. Error bars represent ± one standard deviation (SD). There is no significant difference between CISS score for the SPECT and SVCL (p = 1.0). Significant differences were found between LAMFCL versus SPECT and SVCL (p < 0.01) and HAMFCL versus SPECT and SVCL (p < 0.01). No difference in the CISS scores was found between LAMFCL and HAMFCL.

Possible changes to the lag of accommodation were also evaluated for the four test conditions of each eye as stated above. Paired sample t-tests were conducted and found no significant difference in the lag of accommodation between pre and post wearing of each type of CL for each eye; therefore, the mean accommodative lag results of post-lens wear were used for analysis.

By comparing the mean values of the lag of accommodation of each eye for all the four test conditions (Figure 16), there was no statistically significant difference found for the RE, $F (3,69) = 2.68$, $p = 0.05$, partial $n^2 = 0.10$, and the LE, $F (3,69) = 2.41$, $p = 0.07$, partial $n^2 = 0.10$. Although no statistically significant difference was found, slight changes to the lag of accommodation with the MFSCLs when comparing to the SVCL were observed. The lag of accommodation for the RE after wearing the LAMFCL was 1.63 (SD 0.50), whereas the LE was 1.65 (SD 0.47). The result was slightly lower when compared to the accommodative lag result after wearing SVCL, which was 1.67 (SD 0.36) and 1.68 (SD 0.38), for the RE and LE, respectively. A lower mean value of the lag of accommodation was also observed with the HAMFCL versus SVCL for both the RE [1.43 (SD 0.61) vs 1.67 (SD 0.36)] and the LE [1.51 (SD 0.46) vs 1.68 (SD 0.38)], which brings the accommodative lag result very close to the mean value of the SPECT condition, which was about 1.52 (SD 0.48) for the RE and 1.49 (SD 0.34) for the LE.

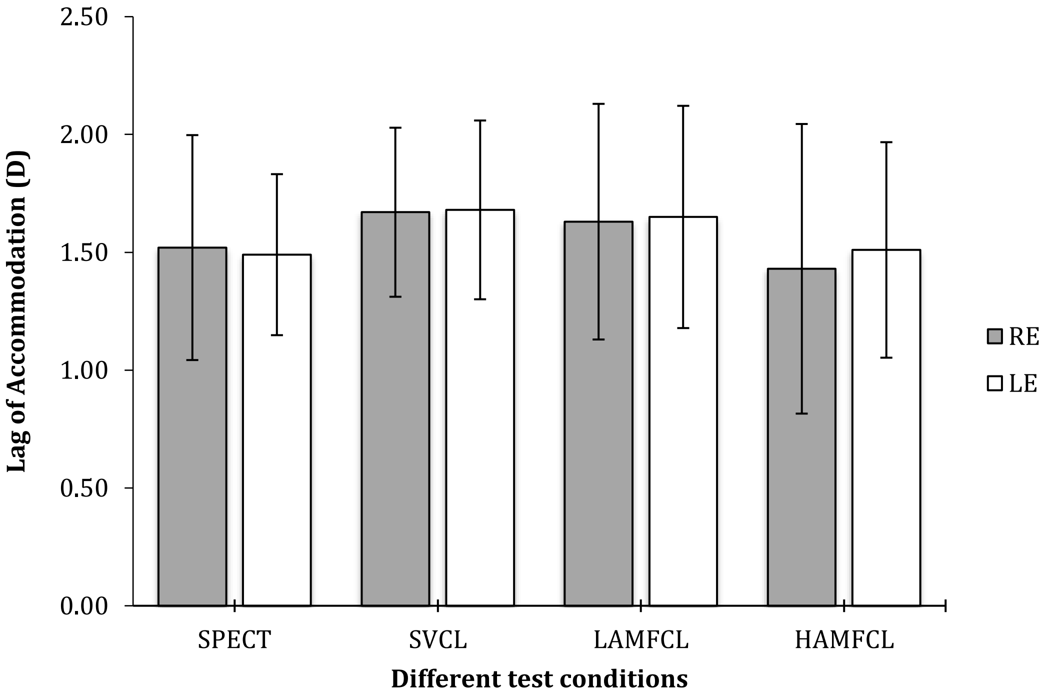


Figure 16. Bar chart representing the mean values of the lag of accommodation for RE and LE for each test condition regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). There was no statistically significant difference between the lag of accommodation for the RE ($p = 0.05$) and the LE ($p = 0.07$) for the four test conditions.

Analysis of both distance and near heterophoria was conducted using similar steps as for the analysis of lag of accommodation. Mean distance phoria illustrates statistically significant changes between the tests conditions, $F (3,69) = 7.10$, $p < 0.01$, partial $n^2 = 0.24$. *Post hoc* analysis using Bonferroni correction indicated differences were found between SPECT versus SVCLs [0.04 (SD 1.66) vs 1.38 (SD 1.61), $p = 0.01$] and HAMFCLs [0.04 (SD 1.66) vs 1.17 (SD 1.54), $p = 0.02$]. When comparing the mean distance phoria change between SPECT and LAMFCLs, there was no significant difference between them [0.04 (SD 1.66) vs 0.90 (SD 1.50), $p = 0.11$]. The overall result shows that the distance phoria was more esophoric when switching from SPECT to all the other CLs used in the study, with SVCLs showing the highest shift in esophoric direction. Both LAMFCLs and HAMFCLs mean distance phoria were slightly less esophoric when comparing to the SVCLs, which means that the eyes were shifting slightly towards the exophoric direction. Ultimately, the heterophoric values of both LAMFCLs and HAMFCLs were still higher than SPECT (Figure 17).

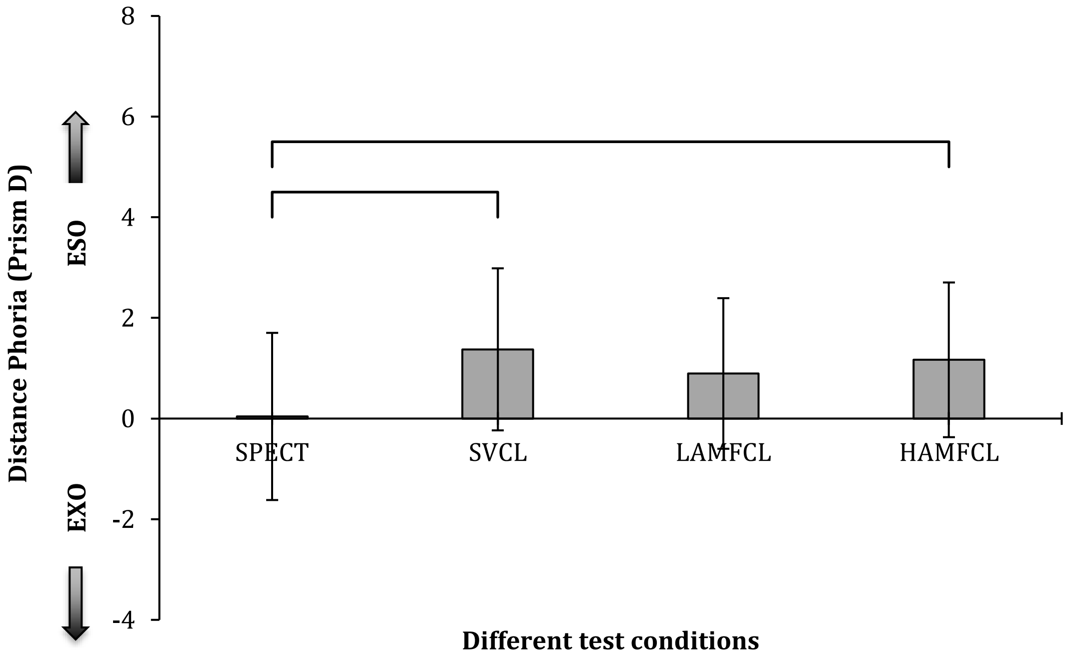


Figure 17. Bar chart representing the mean values of distance phoria for each test condition regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). A statistically significant difference was found between the mean distance phoria for the four test conditions ($p < 0.01$). A significant difference was found when comparing the mean distance phoria between SPECT versus SVCL and HAMFCL ($p = 0.01$). Both LAMFCL and HAMFCL show a slight shift towards the exophoric direction when comparing to the SVCL condition.

The mean near phoria on the other hand shows a statistical results value approaching significance, $F (1.90, 43.78) = 3.13$, $p=0.056$, partial $n^2 = 0.12$. The finding shows a very similar trend to the distance phoria condition, where heterophoria shift in the esophoric direction was observed when changing from SPECT [1.38 (SD 2.02)] to SVCLs [2.17 (SD 2.91)], with no significant difference between them (Figure 18). When comparing the mean near phoria of both LAMFCLs and HAMFCLs to SVCLs, *Post hoc* analysis using the Bonferroni correction shows significant differences detected between them [0.83 (SD 3.51) vs 0.94 (SD 3.11) vs 2.17 (SD 2.91), respectively, p = 0.02].

The results indicated a lesser shift in the esophoric direction for both LAMFCLs and HAMFCLs, which was similarly seen in the distance phoria result when comparing SVCLs to both LAMFCLs and HAMFCLs. However, a larger shift towards the exophoric direction was observed for the near phoria of LAMFCLs and HAMFCLs, resulting in the mean near phoria of both MFSCLs having a lower mean result when comparing to the SPECT [0.83 (SD 3.51) vs 0.94 (SD 3.11) vs 1.38 (SD 2.01), respectively, p = 1.00] (Figure 18).

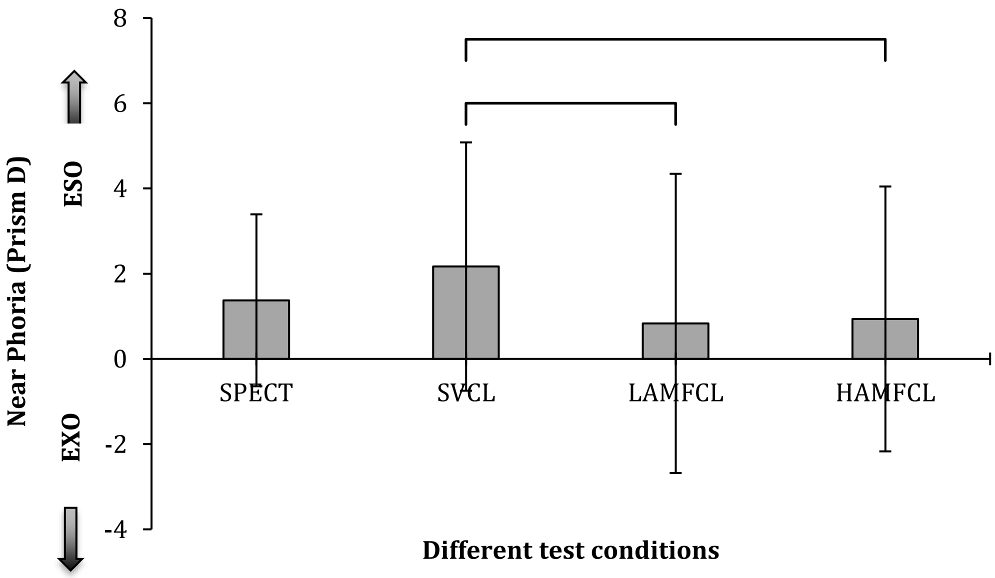


Figure 18. Bar chart representing the mean values of near phoria for each test condition regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). Generally, there was no statistically significant difference found between the near phoria for the four test conditions (p = 0.056). *Post hoc* analysis indicated that a significant difference was found only when comparing LAMFCLs with SVCLs (p = 0.02) and HAMFCLs with SVCLs (p = 0.02). No different was found between both MFSCLs and when comparing both MFSCLs to SPECT. The LAMFCLs and HAMFCLs show phoria values lower than both SPECT and SVCLs, which indicates a shift towards the exophoric direction.

3.5 Discussion

The main finding of this study was that pre-presbyopic orthophoric and esophoric individuals with symptoms of asthenopia show improvement in their asthenopic symptoms after wearing centre-near design MFSCLs; this was demonstrated by the decrease in the CISS score after wearing the MFSCLs.

To determine whether the visual therapy prescribed is effective, a grading scale should be used to obtain the symptom score before and after the intervention was administered (Scheiman and Wick, 2014). The CISS form was chosen for this study because it consists of questions with regards to near visual complaints that an optometrist commonly asks during an eye examination (García-Muñoz et al., 2014; Lambooij et al., 2010; Rouse et al., 2004). Also, the CISS form has been validated and shown good validity and reliability. Besides that, Scheiman and Wick (2014) have suggested CISS form can be used as symptom questionnaires for other binocular vision and accommodative disorder.

The average CISS symptoms' score for participants wearing SPECT and SVCLs were very similar; 25.04 (SD 4.58) and 24.46 (SD 4.59), respectively. However, after wearing the centre-near MFSCLs, the CISS score improved to 12.17 (SD 6.90) and 13.71 (SD 7.23) for the LAMFCLs and HAMFCLs, respectively. The results indicate that participants feel more comfortable conducting near tasks while wearing centre-near MFSCLs.

The study finding was very similar to Jong and colleagues' (2011) study, where 26 university students, fitted with centre-near MFSCLs, reported that they preferred and were satisfied with the use of MFSCLs for near work because they felt that MFSCLs provided better visual performance during near tasks. However, the authors recruited asymptomatic participants and the type of survey form used in their study was likely different from this study. Nonetheless, their conclusion does align with this study result showing that centre-near MFSCLs did improve the visual comfort of their participants at near, especially for reading.

Some studies that were conducted to investigate the effect of MFSCLs near addition power on the accommodative lag of pre-presbyopes show inconsistent findings. Pettersson et al. (2011), using centre-distance MFSCLs on 20 pre-presbyopic participants, show that MFSCLs did not relax the accommodation. Madrid-Costa et al.'s (2011) using centre-near MFSCLs on ten pre-presbyopic adults also concluded that no significant difference in the lag of accommodation was observed when comparing three different near addition MFSCLs to SVCLs.

A study by Barodawala and Dave (2014) reported that accommodative lag was increased in their myopic participants pre and post wearing of MFSCLs. Kang and Wildsoet (2016) using centre-distance MFSCLs also found an increase in the lag of accommodation for both MFSCLs with addition power of +1.50 D and +3.00 D. However, the increase in accommodative lag was no longer apparent after two weeks of wearing the MFSCLs, leading to the conclusion that participants might have adapted to the CL design. Similarly, increased accommodative lag while wearing of MFSCLs as compared to SVCLs was reported by Gong et al. (2017), who fitted centre-distance MFSCLs on young children aged 12−15 years. Based on the results, the author suggested that the children in their study were responding either to the near addition power or the increased depth-of-focus created by the MFSCLs. In turn, this lessened the need for accommodation, and thereby decreased the accommodative response.

Lee and colleagues (2015), using centre-near MFSCLs, found a reduction in the accommodative lag when comparing MFSCLs to single vision, monovision and modified monovision CLs over four different stimulus test distances. Accommodative response was found to be much better with MFSCLs comparing to single vision and monovision CLs in the 2.5 D stimulus distance, indicating lower accommodative lag as compared to the other two test lenses. However, the difference was only statistically significant between the MFSCLs and the monovision lens but not with the SVCLs. A bifocal soft CLs study by Tarrant et al. (2008) on emmetropic and myopic young adults showed that simultaneous image CLs decrease lag of accommodation. The reduction in accommodative lag was even larger than the SVN CLs, which was reduced by 1.5 D over the full distance power.

In this current study, the accommodative lag observed using MEM retinoscopy on pre-presbyopic participants while wearing centre-near MFSCLs, shows that there was no statistically significant difference in the lag of accommodation between SPECT, SVCL, LAMFCL and HAMFCL. The results are consistent with Pettersson et al. (2011), Madrid-Costa et al. (2011) and Kang and Wildsoet (2016).

The possible reason for the statistically insignificant changes to the lag of accommodation found in this study might be due to the pupil size. Young adult pupil size under photopic condition may vary from 2−4 mm diameter and mesopic condition 4−8 mm in diameter (Spector, 1990). Cardon and Lópex (2016) reported that the average pupil diameter when conducting reading (33 cm) and computer tasks (60 cm) to be about 3 mm in diameter; the pupil size information was collected using real life working tasks, working distance and room lighting.

Additionally, due to commercial secrecy, the actual design of most MFSCL is not entirely explained by the manufacturers. What is provided to the practitioners mostly is the detail that the MFSCLs incorporated the concept of simultaneous focus, which induced multiple powers at the centre of the pupil. Other information included describing whether the CL is centre distance or near, the refractive power of the distance prescription and the nominal addition power (Montés-Micó et al., 2014). Little information is provided regarding the dimension of the near portion and the actual positive power at a certain radius of the lens diameter.

The power profile of the centre-near MFSCLs used in this study was investigated by Montés-Micó et al. study (2014). It was found that LAMFCL and HAMFCL have a centre-near zone of 3.0 mm and 3.6 mm, respectively, indicating that a pupil diameter of at least 3.0 mm and 3.6 mm is required to respond to the near addition power of the LAMFCL and HAMFCL, respectively. However, even with a pupil diameter of 3.0 mm and 3.6 mm, it does not mean that the full addition power of the lens can be fully utilised. Because centre-near MFSCL has the highest positive power closer to the centre of the CL, it will largely depend on the ability of the pupil constriction, the environment lighting and the distance of the target to determine the amount of near add that can be utilised by an individual.

The average participants' photopic pupil diameter in this study was 3.96 mm (SD 0.57) for the RE and 4.00 mm (SD 0.61) for the LE, while the mesopic pupil diameter was 4.97 mm (SD 0.65) for the RE and 5.00 mm (SD 0.60) for the LE (Table 5). Based on Montés-Micó et al. (2014) MFSCLs power profile study, some of the participant's pupil size in this study, under normal room lighting conditions, may not have constricted enough to move into the higher positive power near zone, and therefore did not create a statistically significant change to the lag of accommodation.

In this study, heterophoria condition of the eyes was also investigated when switching from spectacle to CLs. When a myopes views through a spectacle lens, which is fitted to the distance PD during near task, the visual axis is directed through a base-in prism. Theoretically, this prism would shift the heterophoria towards being more esophoric (Scheiman and Wick, 2014). Therefore, CL wear should decrease the shift of heterophoria towards convergence direction due to the absence of the ophthalmic prism.

Nonetheless, this may not be the case because a base-in prism also theoretically reduces the need for convergence as compared to CL wear. With lesser convergence effort required, it might have resulted in lesser accommodation, and therefore, a lower esophoric finding (Jiménez et al., 2011).

The increase in near esophoria with CLs was confirmed by Jiménez et al. (2011), who reported a shift in the near heterophoria towards convergence direction of about +2.4△ diopters when their participants changed from spectacles to CLs. The optical centre of the ophthalmic lens in their study was adjusted to the participants near PD, eliminating the possibility of the base-in prism affecting their findings. Similarly, the near phoria of participants in this study also exhibited a shift towards a more esophoric direction when changing from SPECT to SVCLs (Figure 18). However, the ophthalmic optical centre was not adjusted to the participants' near PD during near phoria measurement, so that more realistic information can be obtained regarding near heterophoric changes in this study for clinical use.

Statistically significant changes to the distance heterophoria condition towards the esophoric direction were similarly found when switching from SPECT to SVCLs in this study. All participants were looking through the optical centre of the ophthalmic lenses with zero prismatic effect. Therefore, the changes may be due to the retinal image size difference between spectacle versus CL wear, which is due to the fact that all of the participants are myopic and switching the corrective method from ophthalmic lenses to CLs can induce a magnification change in the retinal image size (Charman, 2016). With increased image size, the object will appear closer to the participants, and therefore, greater convergence and accommodation effort are required during the test of distance phoria (Jiménez et al., 2011). Distance esophoric shift was also observed for both the LAMFCL and HAMFCL when compared to SPECT, but the difference was slightly lower as compared to SVCLs.

When analysing the findings of both distance and near heterophoria, it could be noticed that the difference in esophoria, when switching from SPECT to SVCLs, was greater at distance. Based on vergence interactions, the opposite would be expected when changing from SPECT to SVCLs because of the presence of the base-in prism at near with SPECT. One of the possibilities was that some of the participants might be either orthophoric or exophoric at distance, but all participants were definitely orthophoric or esophoric at near. Therefore, due to the heterophoric condition difference at distance and near, it might have resulted in a greater heterophoria finding difference between SPECT and SVCLs for distance than at near. The presence of the base-in prism in SPECT might be another possible explanation for the increased near esophoria finding observed, which indirectly decreases the difference in heterophoria finding between SPECT to SVCLs at near. Therefore, due to these reasons, it might have created a larger difference seen between the heterophoria finding when changing from SPECT to SVCLs for distance than near (Scheiman and Wick, 2014). Currently, there is still a lack of consensus between the latter reason proposed here and the theory of vergence interaction.

As previously mentioned, the findings of this study show that MFSCLs were able to alleviate the symptoms of asthenopia in orthophoric and esophoric symptomatic pre-presbyopic myopes with lag of accommodation. Accommodative lag, when refractive error is fully corrected, is higher for myopes than emmetropes (Ong and Ciuffreda, 1997; Rosenfield and Abraham-Cohen, 1999) and the amount of lag of accommodation can increase when a person changes from spectacles to CLs (Jiménez et al., 2011). Therefore, there was a suggestion that lag of accommodation may be a factor that can result in asthenopic symptoms to an individual (Chase et al., 2009; Sheedy et al., 2003; Tosha et al., 2009).

However, in this study finding, improvement to the participants' symptoms' score was observed after wearing MFSCLs, but there were no statistically significant differences in lag of accommodation for both RE and LE when comparing to either SPECT, SVCLs and both MFSCLs wear. One possible explanation might be that the asthenopic symptoms were alleviated due the slight reduction in the accommodative lag observed, along with the near exophoric shift with MFSCL wear. Although the changes to the accommodative lag after one month of wearing either the LAMFCL or HAMFCL were not statistically significant, slight lowering of the accommodative lag could still be observed.

With MFSCL wear, near phoria in this study could be seen to shifted towards the divergence direction; this exophoric shift, although statistically insignificant, could be an indication suggesting that the accommodation of participants in the study was relaxed by the near addition incorporated in the MFSCLs. Similarly, in Kang and Wildsoet study (2016), a near exophoric shift of 3.69 △ diopters was also observed without any significant changes to the lag of accommodation detected. Gong et al. (2017) also reported a similar near exophoric shift with MFSCL wear, but with accommodative lag elevation in their participants. The author explained that one of the reasons for the exophoric shift might be due to the relaxation of the accommodation by the MFSCLs' near addition power.

Generally, heterophoric shift depends largely on the AC/A ratio. For example, a person with AC/A ratio of 6 △ diopters will have their phoria changed by 1.5 △ diopters even with just a 0.25 D of change to their accommodation. In this study, the participants' average mean AC/A ratio for all four test conditions was approximately 3.27 (Table 4). Therefore, even with a 0.25 D change in accommodation, it will result in a 0.82 △ diopter change to the phoria, which is close to 1 △ diopter of changes. Even though it was previously mentioned that the participants' pupil aperture in this study might not have constricted to the higher positive power of the MFSCLs, the eye may still be viewing though a small amount of the near addition power of the MFSCL, which creates a minimum amount of relaxation to the accommodation, resulting in the observed phoria changes in the finding.

With the slight modification to the accommodative lag in each eye, there may be a summation effect, which improves the near focusing when viewing near work binocularly. Plainis et al. (2013) had reported that visual performance was much better when viewing binocularly compared to monocularly with MFSCL wear, and the author indicated that the improvement was due to the binocular summation, which enhanced the superimposed multiple images on the retina. It was also highlighted in the study that the improvement of the visual performance could not be predicted using objective or computational techniques (Planis et al., 2013).

All the data were collected based on each visit to the research centre and did not take into account each participant's lifestyle usage of these CLs. Because individual visual demand may differ (i.e. their working distance and lighting may vary), these could result in pupil size variation throughout the day as compared to the pupil size during accommodative lag measurement in the research centre, where the testing distance was set at 40 cm with an illumination of about 400 lux. Also, due to modern society changes and how the font size and working distance of individuals decreases when conducting near tasks (Bababekova et al., 2011; Long et al., 2017), it can result in a mismatch in the vergence and accommodation system, in which the eyes are converging closer than accommodation; this mismatch can cause stress to the visual system and leads to symptoms of asthenopia (Brinbaum, 2008).

Due to the minimal changes in the accommodation ability, therefore, which improves the near focusing, and the divergent shift with MFSCL wear at near, it might have reduced the near point stress because of the decreased mismatch of vergence and accommodation system. The combination of improved focusing ability and change in heterophoria may lead to the improvement in the CISS symptoms score while wearing MFSCLs versus SPECT and SVCLs wear.

Another possible explanation for the improvement in the symptom score with MFSCLs wear but not with SPECT and SVCLs might be due to the negative SA induced by the centre-near MFSCLs. SA is a condition whereby there is a lack of coincidence of the light ray focus between the peripheral rays and the central ray (Wahlberg et al., 2011). It was also known that in young adults, the amount of SA is low due to the positive SA of the cornea being compensated by the negative SA of the crystalline lens. However, as reported in studies (Amano et la., 2004; Majid, 2010) conducted with subjects aged between 18 – 69 years, it was found that as the crystalline lens ages, the amount of positive SA increases. The amount of SA will also change linearly with accommodation, from positive values during unaccommodated condition towards more negative ones in the accommodated condition (Wahlberg et al., 2011).

SA, whether positive or negative, has been known to increase the depth-of-focus (Bakaraju et al., 2010a). It was also shown that a higher level of negative SA resulted in a slightly higher level of depth-of-focus when compared to positive SA (Bakaraju et al., 2010a; Fedtke et al., 2017). Because all the participants in this study were aged between 18−35 years, therefore, the amount of SA in an unaccommodated condition can be assumed to be in the positive range and becomes negative in the accommodated condition. The MFSCLs used in this study were all centre-near design and the lens was found to induce negative SA (Fedtke et al., 2017). Therefore, when this external optical component was added to the visual system of the participants in the study, it might have created a larger negative SA during accommodation at near. With the increase in the negative SA, it indirectly causes an increase in the depth-of-focus, which may have resulted in a reduction to the perception of blur during near reading.

According to the Cambridge Anti-Myopia Study (CAMS), inducing negative SA using CLs reduces the accommodative lag, thereby improving the accuracy of the accommodative response for proximal targets (Allen et al., 2009). However, in this study, negative SA was also created by the centre-near MFSCLs during near reading but without significant changes to the accommodative lag. Besides that, Tarrant et al. (2010) demonstrated that with the presence of negative SA, accommodative lag might serve to decrease the retinal blur image in an accommodating eye, producing a relatively clear image. Other studies (Applegat et al, 2003; Chen et al., 2005; Cheng et al., 2004; Tarrant, 2010) have also highlighted that with specific combination of negative SA and accommodative lag, it can produce an image that was subjectively better focused than in situations where the same amount of SA or defocus is used alone. Hence, the increase in the negative SA and the combination of accommodative lag, possibly improves the blurred retinal image at near, thereby reducing the symptoms' score of the participants. Likewise, as explained in the previous study by Gong et al. (2017), the presence of SA enlarged the depth-of-focus causing an increased range of clear vision, which might have lessened the need for accommodation, therefore resulting in the slight exophoric shift with MFSCL wear observed in this study.

Alternatively, the improvement in the symptom score may be due to bias. Although the optometrist and the all the participants were masked to the randomisation of the CL order, participants may have been able to identify the difference between the CLs, based on the visual difference between MFSCLs and SVCLs. Due to that, it may have resulted in participants psychologically feeling that their vision is definitely 'better' and more relaxed when comparing to their spectacle and SVCLs.

One of the limitations in this study involved the difficulties in gathering information regarding the illumination level around the area where each participant conducts most of their daily visual tasks: this leads to the conclusion that variation in the lighting level, resulting in further constriction in pupil size, thereby allowing a higher amount of near addition being utilised, cannot be confirmed. Collection of information on the illumination level should be incorporated in future work by requesting participants to record the illumination level of the area where they spend the most hours conducting their near visual tasks by using a light meter.

Another consideration would be to measure accommodative lag using the working distance that each participant usually conducts their near visual activities (i.e., using their mobile phone, tablets, computer, etc.). By doing so, it will provide more realistic information regarding the lag of accommodation for that particular working distance and target size. The accommodative lag can also be compared with the lag of accommodation of the same participant at 40 cm to determine whether there is any significant difference when the distance varies.

Because this study only recruited asthenopic symptomatic myopic participants with esophoric or orthophoric conditions, it would be interesting in future work to include exophoric myopic symptomatic participants to determine whether MFSCLs would also alleviate their symptoms. Also, the MFSCLs used in this study were mainly centre-near designs. It would be interesting to conduct a study using center-distance MFSCLs to evaluate its effect on asthenopic symptomatic myopic participants with esophoric or orthophoric conditions, since pre-presbyopic patients may have a larger pupil diameter compared to presbyopic ones.

Some other improvement to this study that should be consider includes:

1. Associated near heterophoria.

In this study, the use of Maddox wing for near heterophoria measurement provided results under dissociated condition (Scheimen and Wick, 2014). The testing method was conducted without fusion; therefore, it may not be able to truly reflect how the visual system works under natural binocular conditions. Near heterophoria testing was conducted using Maddox wing in this study because it is a common method used in Singapore optometric practice. Future work should investigate the participants associated near heterophoria using method such as the Mallett unit. Associated heterophoria result is gather under binocular vision condition therefore, the testing condition will be more natural, thereby providing a more realistic and meaningful clinical data (Scheimen and Wick, 2014). It was also indicated that associated heterophoria testing is a more effective method to determine the amount of prism required for treatment of binocular vision disorder (Scheimen and Wick, 2014). In fact, Yekta et al. (1989) in their study found significant correlations between asthenopic complaints with associated heterophoria and not with dissociated heterophoria.

2. Randomisation of participants

Participants in this study were randomised by a colleague working in the practice. Although this simple randomisation procedure is one of the basic methods, it might not be the best randomisation technique to prevent selection bias (Kim and Shin, 2014). Alternatively, randomisation can be achieved by using excel spreadsheet. By generating a random number for the 24 participants, the random number can be sort by ascending or descending format and allocating them to either Group one or two. This allocation method will significantly reduce the factor regarding researchers influencing which participants are assigned to which group (Kim and Shin, 2014).

3. Intra-examiner reliability

Even though only one examiner conducted all the clinical tests in this study, no intra-examiner reliability was assessed. Domholdt (1993) defined that intra-examiner reliability is the consistency with which one examiner assigns scores to a single set of responses on two or more occasions (Jonson and Gross, 1997). Without assessing the examiner measurement reliability, it will be difficult to determine the consistency and the error component of the measurement; this may result in significant error in the clinical outcome measurement, thereby affecting the overall result of the study (Jonson and Gross, 1997). A pilot study should be conducted to determine the intra-examiner reliability before commencing the actual research in future study. If the measurement result shows inconsistency, the examiner should be retrained on the technique (e.g. MEM retinoscopy) until the error component is small, thus allowing a more consistent estimation of the true measurement.

4. Washout period between MFSCLs wear

The MFSCLs addition that the participants wore were swapped after one month of wearing. A washout period was not considered during the design of this study methodology. Due to the absence of washout period between each lens type, it may not have prevented any learning effect or biases related to the residual adaption effect of the previous MFSCLs. Therefore, in future study, a washout period of at least a week between each type of CLs fitted should be considered, or a SV CLs can be fitted and wear for a month after wearing MFSCLs before switching over the other addition.

5. Compliance with CLs wear

As mentioned in section 3.2.1, participants were told to wear the lens for five days a week and at least eight hours a day. During each visit, participants were asked how many days they wore the CLs a week and how many hours did they wore the CLs each day. In this study, there was no actual method design to measure the compliance of participants with CLs wear. One possible method is to request the participant to keep a diary on the date and hours for their CLs wear and recording down information on their experience with the CLs each day (e.g. comfort of lens, vision, etc.). By doing this, it may improve the compliance of CLs wear in this study. However, this may still not be able to entirely prevent participants from being non-compliance with the CLs wear as information can still be fabricated. Generally, monitoring participants compliance in any clinical trial can be challenging and there may not be a completely satisfactory method to assess the compliance (Pullar et al., 1989; Spilker, 1992).

6. Effect size for sample calculation

Effect size refers to the magnitude of the difference between groups (Sullivan and Feinn, 2012). The difference between the mean outcome measures in two different intervention groups is referred to the absolute effect size. In any quantitative study, a P value indicates a statistically significant difference is detected, but it does not reveal the magnitude of the effect (Sullivan and Feinn, 2012).

Before beginning any study, a sample size calculation is required; this is to ensure that the research has sufficient power to avoid Type II error. Power calculation requires an estimated effect size. One possible method that can be used to estimate the effect size is by using the effect size from similar work previously published (Sullivan and Feinn, 2012). However, no similar study was conducted prior to this study.

The effect size used for sample calculation in this study was 0.4. Based on the general guide developed by Cohen (Cohen's d), the effect size of this study was close to the moderate effect range. With a medium effect size range, any significant differences after wearing MFSCLs indicates that the finding is meaningful as there is moderate effect after wearing the contact lenses. An effect size of 0.4 can be considered a little low. Therefore, future study should consider the use of larger effect size to determine if there is statistically significant difference in the finding.

3.6 Conclusion

The finding in this study shows that when comparing SPECT and SVCLs to both the LAMFCLs and HAMFCLs, improvement to the asthenopic symptoms of participants was observed based on the reduction in the mean CISS score. There was no statistically significant difference found with the CISS score when modifying the amount of MFSCLs' near addition, suggesting that changing the amount of MFSCLs' near addition did not further improve the asthenopic symptoms of the participants.

The result of this study suggests that both orthophoric and esophoric myopes do not use the near addition power provided by MFSCLs to replace their accommodative activity, and do not create a significant change in the phoric status at near. The improvement in the CISS symptoms' score may have resulted from the depth-of-focus created by negative SA from the MFSCLs, which might have aided in tolerating the minor degradation of image quality that would be easily reported as a complaint during single vision device usage. Further work is required to conclude the effectiveness of MFSCLs on ocular asthenopia.

4.0 Accommodation Response of Pre-presbyopic Myopes after one month of wearing Multifocal Soft Contact Lenses (MFSCLs)

4.1 Introduction

Studies have been conducted on pre-presbyopic myopes wearing MFSCLs for different reasons. Some of the studies (Lee et al., 2015; Madrid-Costa et al., 2011; Pettersson et al., 2011) investigated the accommodation response of young adults and adolescent wearing MFSCLs, while others (Gong et al., 2017; Kang et al., 2015; Kang and Wildsoet, 2016) have investigated the effect of MFSCLs on accommodation and visual function in young adults and children for myopia control.

Regardless of the purposes, all authors reported findings on accommodation responses of pre-presbyopic individuals while wearing MFSCLs'. However, there were different conclusions regarding the effects of MFSCLs near addition on the accommodative responses. Three studies (Kang and Wildsoet, 2016; Madrid-Costa et al., 2011; Pettersson et al., 2011) have shown that MFSCLs do not induce changes in the accommodative response, while one study (Gong et al., 2017) shows that accommodative response was modified. The variation in the conclusion may be due to three reasons: 1) differences in the lens type use, 2) the adaptation period for the participant wearing the MFSCLs, and 3) the use of objective methods in data collection.

In Pettersson and colleagues' study (2011), participants were given only four hours of adaptation time after MFSCLs were fitted before any measurements were conducted, whereas Madrid-Costa et al. (2011) and Gong et al. (2017)

either gave no adaptation time, or only up to ten minutes of settling time to participants after MFSCLs were fitted. On the other hand, Kang and Wildsoet (2016) allowed participants to wear each type of the MFSCLs for two weeks, before any research data were collected. However, the adaptation period may still be insufficient for the MFSCLs to induce any changes in the participants' accommodative response.

Montés-Mićo and colleagues (2003) suggested that adaptation time is a crucial factor in wearing simultaneous focus design lens. They observed that multifocal intraocular lenses resulted in decreased contrast sensitivity for both distant and near vision initially. However, contrast sensitivity gradually improved and became stable at 3−6 months postoperatively. The authors suggested that a simultaneous focus design lens required a longer period of adaptation before patients become accustomed to the lens design and adjust to the new imagery created on the retina, thereby allowing the lens to reach its maximum clarity. Fernandes et al. (2013) also reported that their participants' visual acuity (VA) for both distance and near improved after 15 days of wearing MFSCLs, and indicated that the improvement was due to an adaptation to the multifocality over time. Therefore, as the design of MFSCLs used by the above-mentioned studies (Gong et al., 2017; Kang and Wildsoet, 2016; Madrid-Costa et al., 2011; Pettersson et al., 2011) were all simultaneous focus designed, a period of adaptation is definitely necessary before any changes to the accommodative response can be observed (Fernandes et al., 2013; Montés-Mićo and Alió, 2003).

All studies mentioned hitherto used objective methods to collect data on the accommodative response; however, the data collection methodologies were varied, potentially giving rise to the observed differences. Petterson and co-workers (2011) used a Shin-Nippon open-field photorefractor to obtain the accommodative responses for both distance and near vision. The procedure dissociated the eyes by using a septum, and positioned a high-contrast 6/6 Snellen acuity near target at 40 cm in front of the right eye (RE), which was wearing the centre-distance MFSCL. Accommodation was recorded via the left eye (LE), without any contact lens (CL) in place, but with their habitual spectacle correction. Measurement of the accommodation response using this method may have some limitations; for example, the tested LE would be in a converging angle while the RE was looking at the near target place in front of it, and therefore it might result in peripheral refraction being measured producing an over- or under-corrected spherical and cylindrical result (Whatham et al., 2009). Also, accommodation was measured via the contralateral eye, rather than the eye under investigation.

Gong et al. (2017) used a custom-built infrared photorefractor to measure the accommodative response of young children's REs, which were corrected with a single vision contact lens (SVCL) and occluded by an infrared filter. The LE, which was fitted with the centre-distance MFSCL, was able to view the near target placed directly in front of it, and the accommodative response was measured at four different stimulus distances. The measurement method by Gong et al. was very similar to that of Petterson et al.'s study (2011), where the occluded eye was slightly converged during the accommodative measurement using the infrared photorefractor (Seidmann and Schaeffel, 2002); therefore, it might also have incurred a similar limitation as seen in Petterson and colleagues' study.

Madrid-Costa et al. (2011) tested the accommodative response of their participants at 25 cm and 40 cm using centre-near MFSCLs with two add power; low add (up to +1.50 D) and high add (+1.75 or greater). Accommodative response was measured only for the RE using the Hartmann-Shack aberrometer with the LE occluded. According to Kobashi and co-workers (2015), occlusion of one eye can result in having the pupil size larger than when comparing to binocular viewing; this might affect the pupil size measurement results of their study because a change in pupil response was used as an indicator for accommodative response. Also, monocular occlusion could result in poor focusing of the non-occluded eye and destabilise the accommodation response (Stark and Atchison, 2002).

Kang and Wildsoet (2016) measured their participants' accommodative response binocularly using a Complete Ophthalmic Analysis System (COAS) wavefront analyser with an open-field adaptor, while wearing the centre-distance MFSCLs with two different near addition powers: +1.50 D and +3.00 D. The near target was positioned along participants' midline and objective refractions were collected on the axis to the eye. The method utilised in this study was more natural and able to control accommodation better, thereby providing a more reliable result because it reduces the risk of proximal accommodation and allows the real-world targets to be observed with a wider range of field of view (Davies et al., 2003; Hunt et al., 2003; Wan et al., 2012). However, because MFSCLs have power variation from the centre to the lens periphery (see Section 2.6.1), there was no information regarding the pupil diameter used for analysis. According to Bakaraju et al. (2015), accommodative response analysis with a 1 mm different in pupil diameter while wearing MFSCLs can produce variation in results. Therefore, if the pupil diameter used for analysis was not determined, the overall analysis of the accommodative response generated by the wavefront analyser for each participant, while wearing MFSCLs, might have certain variation affecting the overall result (Bakaraju et al., 2015). A summary of the four studies (Gong et al., 2017; Kang and Wildsoet, 2016; Madrid-Costa et al., 2011; Pettersson et al., 2011) can be found in Table 6.

Generally, objective measurement of the accommodation may have superior accuracy. However, one possible disadvantage of using objective measurement might be the difficulty to control participants' fixation and attention. There can always be a possible condition where fixation into or through the refractometer may not be on the target instructed, thereby causing the results to have certain levels of inaccuracy. Besides that, these instruments are not commonly found in general clinical optometric practice. Clinical methods, on the other hand, require the response of the participant and the observation of the examiner; therefore, it can allow better control of participants' fixation and attention.

Studies	Pettersson et al. (2011)	Madrid-Costa et al. (2011)	Kang and Wildsoet (2016)	Gong et al. (2017)
Adaptation Period	Four hours	Up to ten minutes	Two weeks	Up to ten minutes
Instrument	Shin-Nippon Open-field photorefractor	Hartmann-Shack aberrometer	COAS wavefront analyser with open-field adaptor	Custom-built infrared photorefractor
Type of MFSCLs	Centre-distance	Centre-near	Centre-distance	Centre-distance
Methodology for accommodative respond measurement	RE wearing the MFSCLs while the LE wearing habitual spectacle correction; both eyes separated using a physical septum; RE viewing a near target at 40 cm while accommodative response measured via the LE.	RE wearing the MFSCLs and viewing the near target at 40 cm and 25 cm, while LE was occluded. Accommodative response and pupil diameter was measured via the RE.	Both eyes wearing the MFSCLs and viewing near target at 4 m and 33 cm position along the participant's midline while objective refractions were conducted on axis to the RE.	LE wearing the MFSCLs and viewing near target placed directly in front. RE wearing SVCL occluded by infrared filter. Accommodative response was measure via the RE at four different stimulus distances.
Results	No accommodative response differences with or without MFSCLs	No accommodative response differences between SVCLs and MFSCLs.	Increase accommodative lag and near exophoria with MFSCLs wear	Increase accommodative lag and near exophoria with MFSCLs wear
Possible limitation(s)	LE will be in converging angle, which might result in peripheral refraction measured producing over- or under-corrected spherical and cylindrical results.	Monocular occlusion resulted in larger pupil size as compared to binocular viewing, and might affect the pupil response result. Non-occluded eye may also have poor focusing and destabilised the accommodative response	No information regarding the pupil diameter used for analysis. Because MFSCLs have power variation from the centre of the lens to the periphery, it might affect the overall analysis outcome.	Occluded eye slightly converged during accommodative measurement, which might have a similar limitation to that seen in Pettersson and colleagues' study.

Table 6: Table summarising the type of MFSCLs, instruments, methodology, results and the possible limitation of Pettersson et al., Madrid-Costa et al., Kang and Wildsoet and Gong et al. studies, which investigates the accommodative response of pre-presbyopes wearing MFSCLs.

With the understanding that a longer adaptation period for simultaneous image lenses was required to achieve its maximum clarity, and that previous studies (Gong et al., 2017; Kang and Wildsoet, 2016; Madrid-Costa et al., 2011; Pettersson et al., 2011) did not investigate the accommodative responses of young adults wearing MFSCLs for more than a two-week adaptation period. The aim of the current research was to examine whether there are changes to the accommodation response of individuals wearing MFSCLs after a period of one month. The resultant data will provide more information on the accommodative profile of a pre-presbyopic individual wearing MFSCLs after a longer period of adaptation.

In this study, it was hypothesized that MFSCLs with centre-near design lead to decreases in the accommodative response of pre-presbyopic individuals.

4.2 Methods, Material and Clinical Procedures

4.2.1 Methods

A double blind, cross-over study (Figure 14) was conducted at Ong's Optics, a private optometric practice in Singapore, following approval from the Aston University Research Ethics Committee (AU REC). The study adhered to the tenets of the Declaration of Helsinki. Participants recruited for the study in Chapter 3 undertook the tasks in the present study; therefore, the cohort demographic, inclusion criteria, the method of randomisation of participants into two groups and the type of CLs used were the same as discussed in Chapter 3, under sections 3.3.1 and 3.3.2.

Baseline testing to collect all participants' ocular accommodation results was conducted with the participants wearing trial lenses before fitting any CLs that were selected for this study (section 3.2.2). Clinical tests such as amplitude of accommodation (AoA), near point of convergence (NPC), positive relative accommodation (PRA) and negative relative accommodation (NRA) were conducted while participants were wearing their full subjective refraction using trial lenses that were adjusted to their distance pupil distance (PD). These tests were chosen because of the following reasons:

1) They are the most commonly used clinical methods in optometric practices, and
2) They can provide vital information of the accommodative response of the participants, should the test lenses show effectiveness in changing the accommodation response after wearing the MFSCLs for one month.

4.2.2 Amplitude of Accommodation (AoA)

Amplitude of accommodation (AoA) was tested using the RAF rule (Figure 19A) using the push-up and push-down methods (Rosenfield, 2009b). With the participants' full refractive prescription in place and with the LE occluded, they were instructed to focus clearly on the letters on the N5 row of the RAF rule display. The letters chart was moved slowly towards the participants and stopped when the first blurred vision was observed. The participants were asked whether they were able to focus and keep the letters clear. If the participants were able to maintain clarity of the letters, the letters chart continued to move slowly until the letters could no longer be read clearly. The reading on the RAF rule, in diopters (D), was recorded. The letter chart was then moved away from the participants and stopped when they reported the letters first became clear. The test routine was repeated three times and the average of the three measurements was recorded. The same test procedure was repeated for the LE with the RE occluded.

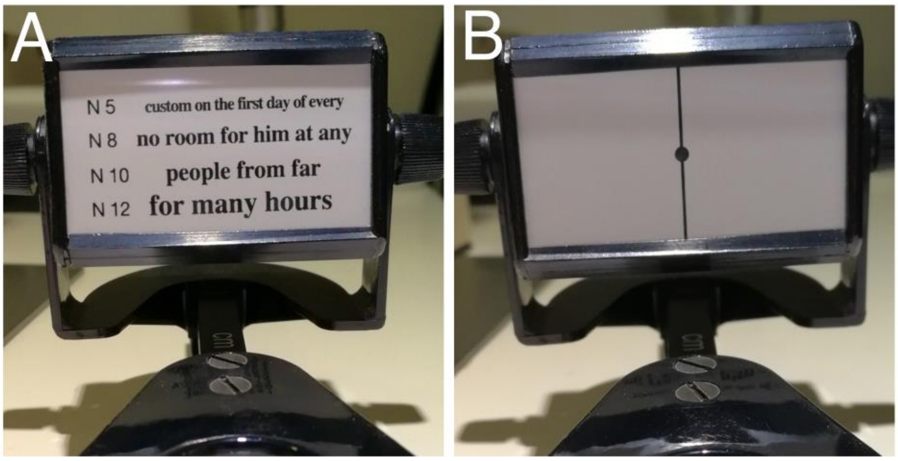


Figure 19: RAF rule used for testing the Amplitude of accommodation (AoA) and Near point of convergence (NPC) in the study. A) Fixation letter used for AoA testing N5. B) Vertical line with centre black dot used for NPC testing.

4.2.3 Near Point of Convergence (NPC)

Near point of convergence (NPC) was conducted using the same RAF rule. Wearing the full refractive prescription, participants were instructed to focus on the vertical line with a centre black dot target on the RAF rule display

(Figure 19B). With both eyes open, participants were instructed to keep the target clear and single at all time as it moved towards them. Participants were instructed to inform the examiner once the target became blurred and/or double, and the reading of the distance where the target stopped was taken off from the RAF rule, in centimetres (cm). This measurement was repeated three times, recorded to the nearest half centimetre and averaged.

4.2.4 Positive and Negative Relative Accommodation (PRA/NRA)

Negative relative accommodation (NRA) was tested using plus lenses inserted into the full prescription that the participant was wearing binocularly. Participants were asked to focus on N5 letters at a distance of 40 cm from the eyes. Plus lenses were placed into the trial frame in 0.25 D steps until the participant reported that the letters became blurred. Participants were asked if they were able to make the letters clear. If they were able to sustain clear vision, further plus lenses were added into the trial frame until the target was no longer clear. The total amount of lens power added was then recorded in diopters (D). Positive relative accommodation (PRA) was performed using the same procedure by using the minus lenses. NRA was tested first before PRA to avoid the minus lenses affecting the accommodation during measurement (Scheiman and Wick, 2014; Yekta et al., 2017).

4.3 Statistical Methods

The cohort size was calculated using G*Power 3.1.3 software (Franz Faul, Universität Kiel, Germany), where the details of the calculation were the same as mentioned in section 3.4. The test method selected is the F test under the Test Family function and using analysis of variance (ANOVA): Repeated measures. Assuming an effect size (f) value of 0.40, an alpha error probability of 0.05, and power as 0.80, the number of groups to be 1 and the number of measurements of 3, with correlation among repeated measures of 0.5 and nonsphericity correction of 1, the total sample size recommended is 12. However, the number was increased to 18 to improve the power to 0.95 and to allow for attrition.

IBM SPSS statistics 23 (IBM corporation, Armonk, New York) was used for statistical analysis. Microsoft Excel 2016 (Microsoft Corporation, Redmond, Washington) was used for data storage.

AoA, NPC, PRA and NRA of all participants were initially compared using the paired sample t-test to determine whether there was any difference between pre and post wearing of each type of CL. Because there was no significant difference between the mean value of the pre and post-lens wear result, the post-lens wearing result for each CL was used to compare against each test condition: spectacle (SPECT), single vision contact lens (SVCL), low addition multifocal contact lens (LAMFCL) and high addition multifocal contact lens (HAMFCL). Repeated measures ANOVA was used to compare the differences among the four different test lens wear with P values of less than 0.05 set as being statistically significant. *Post hoc* tests were analysed using Bonferroni correction to determine which test lens wear resulted in significant differences.

4.4 Result

A total of 24 participants were recruited for this study. All participants were existing CLs wearers, and none of the participants left the study due to discomfort from CL wear. Also, no participants left the study due to unsatisfactory vision from MFSCLs wear.

No significant differences were found when comparing the AoA of the RE for SVCL pre (1) [M= 10.20 (SD 1.74)] and post (2) [M= 10.23 (SD 1.63)] wear; t (23) = -0.18, p = 0.86, LAMFCL pre (1) [M = 11.19 (SD 1.67)] and post (2) [M = 11.67 (SD 1.27)] wear: t (23) = -0.48, p = 0.08 and HAMFCL pre (1) [M = 12.19 (SD 1.67) and post (2) [M = 11.83, (SD 1.20)] wear: t (23) = 1.87, p = 0.07. (Figure 20)

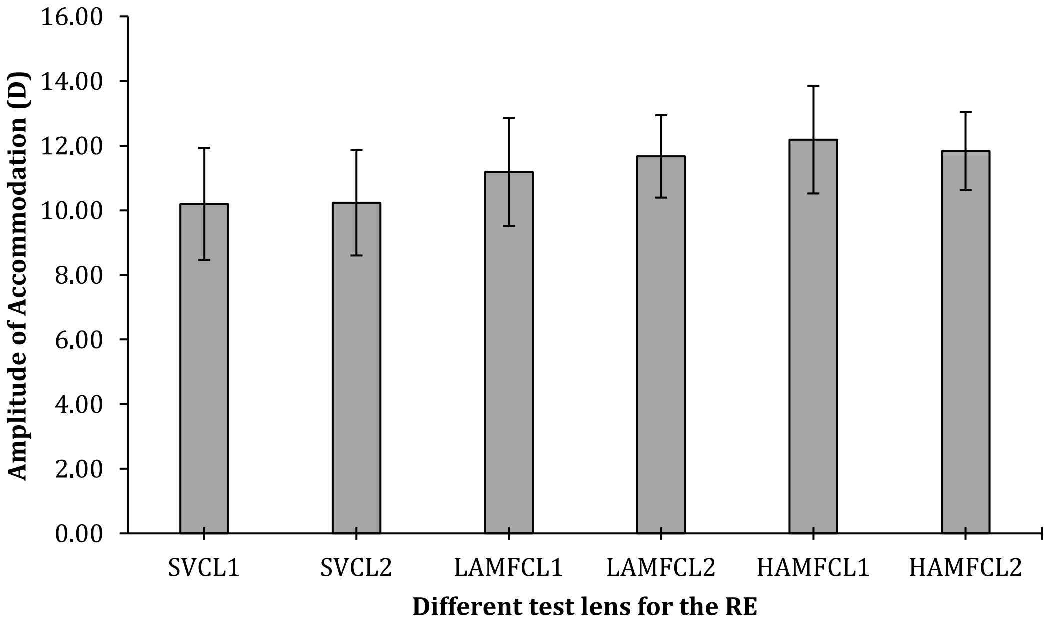


Figure 20: Bar chart representing the Pre (1) and Post (2) mean values of AoA of the RE for each type of CL wear, compared using the paired sample t-test function, regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). There were no significant differences in the AoA found between the pre and post wearing of SVCL (p = 0.86), the LAMFCL lens (p = 0.08) and the HAMFCL (p = 0.07).

There were also no significant differences found when comparing the AoA of the LE for the SVCL pre (1) [M = 10.24 (SD 1.77)] and post (2) [M = 10.31 (SD 1.64)] wear: t (23) = -0.43, p = 0.67, LAMFCL pre (1) [M = 11.15, (SD 1.61)] and post (2) [M = 11.52, (SD 1.25)] wear: t (23) = -1.33, p = 0.20, and HAMFCL pre (1) [M = 12.04 (SD 1.63)] and post (2) [M = 11.67 (SD 1.01)] wear: t (23) = 1.74, p = 0.10 (Figure 21). A summary of the paired sample t-test result for both RE and LE can be found in Table 7.

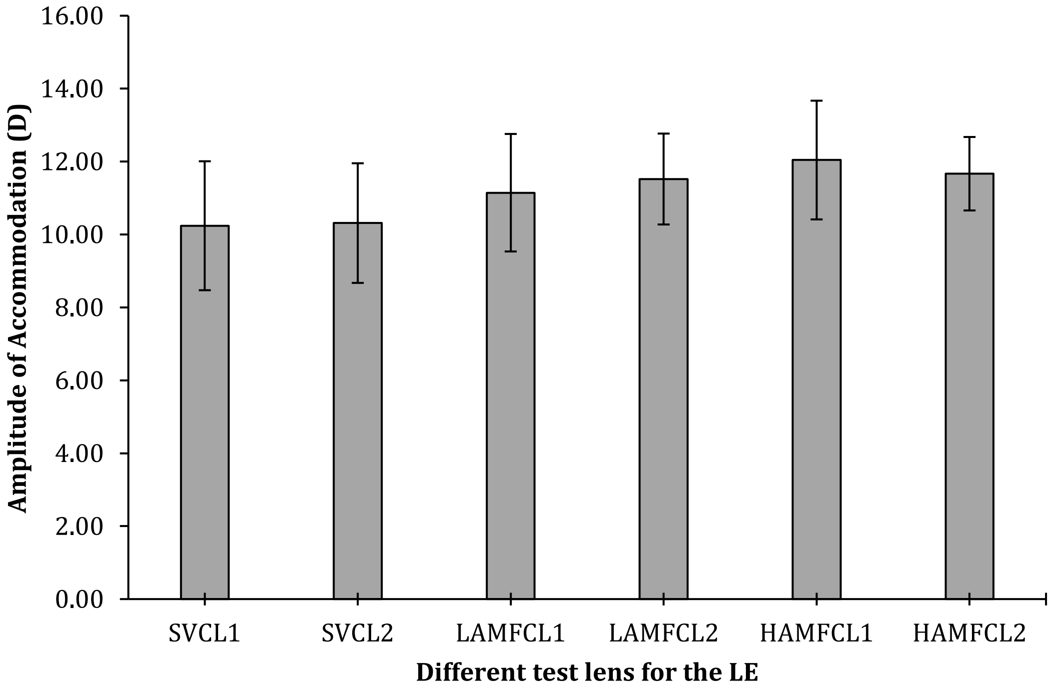


Figure 21: Bar chart representing the Pre (1) and Post (2) mean values of AoA of the LE for each type of CL wear, compared using the paired sample t-test function, regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). There were no significant differences in the AoA found between the pre and post wearing of SVCL (p = 0.67), the LAMFCL (p = 0.20) and the HAMFCL (p = 1.00).

RIGHT EYE Type of lens correction	Pre-lens wear (1) Mean (SD)	Post-lens wear (2) Mean (SD)	Paired t-test Result t(23)	 p value
SVCL	10.20 (1.74)	10.23 (1.63)	-0.18	0.86
LAMFCL	11.19 (1.67)	11.67 (1.27)	-0.48	0.08
HAMFCL	12.19 (1.67)	11.83 (1.20)	1.87	0.07

LEFT EYE Type of lens correction	Pre-lens wear (1) Mean (SD)	Post-lens wear (2) Mean (SD)	Paired t-test Result t(23)	 p value
SVCL	10.24 (1.77)	10.31 (1.64)	-0.43	0.67
LAMFCL	11.15 (1.61)	11.52 (1.25)	-1.33	0.20
HAMFCL	12.04 (1.63)	11.67 (1.01)	1.74	0.10

Table 7. A summary of the paired sample t-test results for SVCL, LAMFCL and HAMFCL Pre (1) and Post (2) wear for the RE and LE.

As no significant differences in the AoA of both the RE and LE were found between the pre and post wearing of each type of lens, post-lens wear mean results were used for analysis using a repeated measure ANOVA test to determine whether there is any difference between the AoA when wearing each test lens. The result indicated a statistically significant difference between the AoA when comparing between SPECT, SVCL, LAMFCL and HAMFCL for the RE, $F\ (3, 69) = 22.58$, $p < 0.01$, partial $n^2 = 0.50$ and the LE, $F\ (3, 69) = 16.53$, $p < 0.01$, partial $n^2 = 0.42$. The results of the AoA for the RE and LE for the four tests lens wear are shown in Figures 22 and 23, respectively. A summary of the results can also be found in Table 8.

Post hoc analysis using the Bonferroni correction (Armstrong et al., 2011) comparing the AoA for the RE between SPECT and SVCL wear shows that there was no statistically significant difference between them [10.28 (SD 1.80) vs 10.23 (SD 1.63), p = 1.00]. However, significant differences were found between the AoA of LAMFCL compared to SPECT and SVCL [11.67 (SD 1.27) vs 10.28 (SD 1.80) vs 10.23 (SD 1.63), respectively, p < 0.01]. The AoA of HAMFCL when compared to SPECT and SVCL also shows a statistically significant difference [11.83 (SD 1.20) vs 10.28 (SD 1.80) vs 10.23 (SD 1.63), respectively, p < 0.01]. There was no significant difference found between the AoA for the LAMFCL and HAMFCL [11.67 (SD 1.27) vs 11.83 (SD 1.20), p = 1.00].

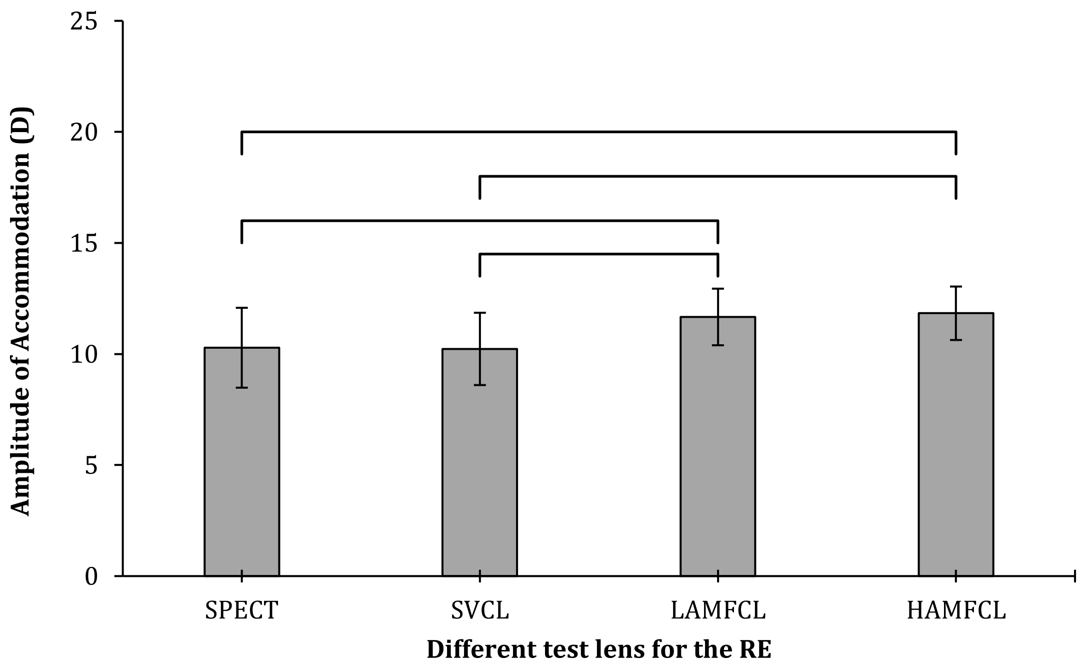


Figure 22. Bar chart representing the mean values of AoA of the RE for each test condition regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). A statistically significant difference was found between the mean AoA for the four different test lenses wear for the RE ($p < 0.01$). *Post hoc* test shows significant differences found when comparing the mean AoA between LAMFCL versus SPECT and SVCL ($p < 0.01$) and HAMFCL versus SPECT and SVCL ($p < 0.01$).

Post hoc analysis using Bonferroni correction comparing the AoA for the LE between SPECT and SVCL wear shows very a similar trend to the RE result.

There was no statistically significant difference found between the AoA for the SPECT and SVCL [10.24 (SD 1.72) vs 10.31 (SD 1.64), $p = 1.00$]. Statistically significant differences were detected between the AoA of LAMFCL compared to SPECT and SVCL [11.52 (SD 1.25) vs 10.24 (SD 1.72) vs 10.31 (SD 1.64), respectively, $p < 0.01$]. Similarly, when comparing the AoA between the HAMFCL to SPECT and SVCL, there were also statistically significantly differences between them [11.67 (SD 1.01) vs 10.24 (SD 1.72) vs 10.31 (SD 1.64), respectively, $p < 0.01$]. There was no significant difference found between the LAMFCL and HAMFCL [11.52 (SD 1.25) vs 11.67 (SD 1.01), $p = 1.00$].

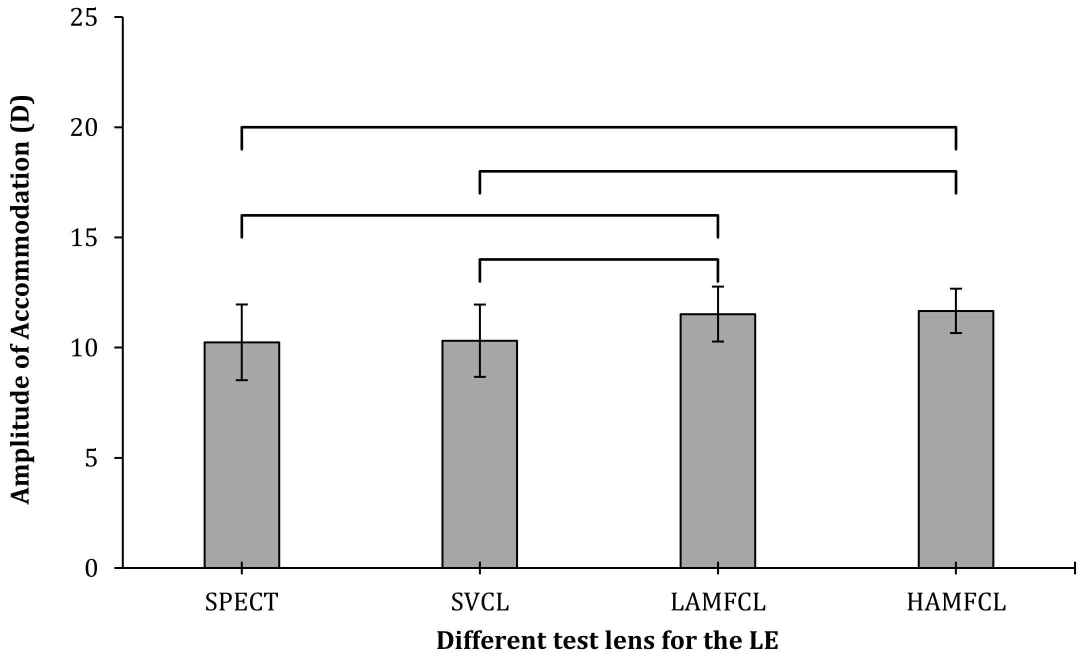


Figure 23. Bar chart representing the mean values of AoA of the LE for each test condition regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). A statistically significant difference was found between the mean AoA for the four different test lenses wear for the left eye ($p < 0.01$). *Post hoc* test shows significant differences found when comparing the mean AoA between LAMFCL versus SPECT and SVCL ($p < 0.01$) and HAMFCL versus SPECT and SVCL ($p < 0.01$).

RIGHT EYE Type of Lens Comparison	**Mean AoA Comparison**	**P Value**
SPECT vs SVCL	10.28 (SD 1.80) vs 10.23 (SD 1.63)	1.00
LAMFCL vs SPECT	11.67 (SD 1.27) vs 10.28 (SD 1.80)	< 0.01*
LAMFCL vs SVCL	11.67 (SD 1.27) vs 10.23 (SD 1.63)	< 0.01*
HAMFCL vs SPECT	11.83 (SD 1.20) vs 10.28 (SD 1.80)	< 0.01*
HAMFCL vs SVCL	11.83 (SD 1.20) vs 10.23 (SD 1.63)	< 0.01*
LAMFCL vs HAMFCL	11.67 (SD 1.27) vs 11.83 (SD 1.20)	1.00

LEFT EYE Type of Lens Comparison	**Mean AoA Comparison**	**P Value**
SPECT vs SVCL	10.24 (SD 1.72) vs 10.31 (SD 1.64)	1.00
LAMFCL vs SPECT	11.52 (SD 1.25) vs 10.24 (SD 1.72)	< 0.01*
LAMFCL vs SVCL	11.52 (SD 1.25) vs 10.31 (SD 1.64)	< 0.01*
HAMFCL vs SPECT	11.67 (SD 1.01) vs 10.24 (SD 1.72)	< 0.01*
HAMFCL vs SVCL	11.67 (SD 1.01) vs 10.31 (SD 1.64)	< 0.01*
LAMFCL vs HAMFCL	11.52 (SD 1.25) vs 11.67 (SD 1.01)	1.00

Table 8. Table showing a summary of the result of the mean AoA for the RE and LE of each type of lens wear and their comparison when analysed using a repeated measure ANOVA test, with a significance value set at <0.05. Results were adjusted using a Bonferroni multiple comparison test: p-value* <0.05.

Paired sample t-tests were conducted to compare the means of the PRA and NRA results between pre and post-lens wear of each type of lens. For the PRA condition, no significant differences were found when comparing between the SVCLs pre (1) [M= -2.76 (SD 0.93)] and post (2) [M= -2.81 (SD

1.01)] wear conditions; t (23) = 0.42, p = 0.68, LAMFCLs pre (1) [M = -3.16 (SD 1.18)] and post (2) [M = -3.22 (SD 1.38)] wear conditions: t (23) = 0.32, p = 0.75 and HAMFCLs pre (1) [M = -3.19 (SD 1.03) and post (2) [M = -3.43, (SD 1.04)] wear conditions: t (23) = 1.70, p = 0.10.

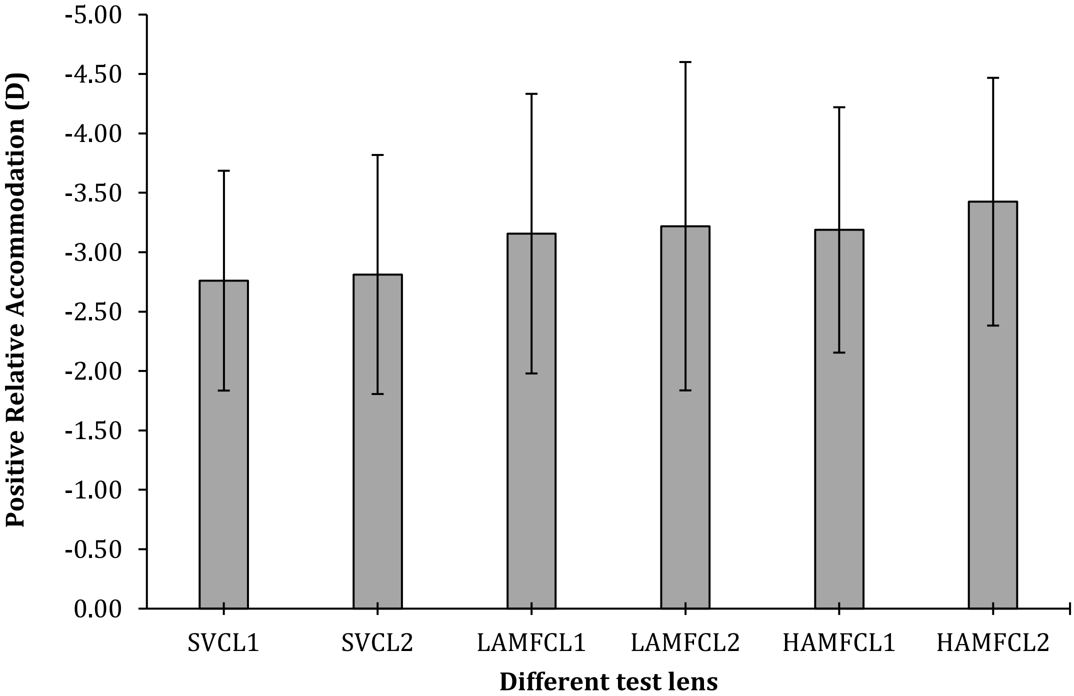


Figure 24: Bar chart representing the mean values of PRA Pre (1) and Post (2) lens wear, when compared using the paired sample t-test function, regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). There were no significant differences in the PRA found between the Pre and Post wearing of SVCLs (p = 0.68), LAMFCLs (p = 0.75) and the HAMFCLs (p = 0.10).

NRA mean results when compared using the paired sample t-test between pre and post lens wear of each type of lens, found no significant differences in the NRA value between the SVCLs pre (1) [M= 2.80 (SD 0.42)] and post (2) [M= 3.00 (SD 0.55)] wear conditions; t (23) = -2.03, p = 0.05, LAMFCLs pre (1) [M = 2.76 (SD 0.46)] and post (2) [M = 2.68 (SD 0.55)] wear conditions: t (23) = 1.02, p = 0.32 and HAMFCLs pre (1) [M = 2.50 (SD 0.62) and post (2) [M = 2.52, (SD 0.49)] wear conditions: t (23) = -0.19, p = 0.85.

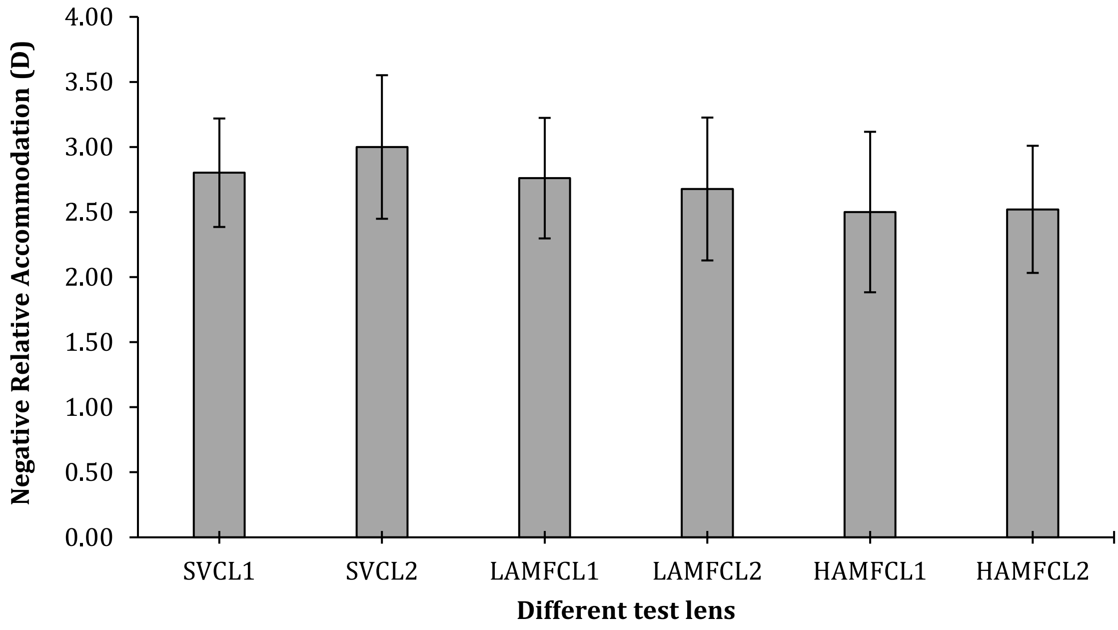


Figure 25: Bar chart representing the mean values of NRA Pre (1) and Post (2) lens wear, when compared using the paired sample t-test function, regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). There were no significant differences in the NRA found between the Pre and Post wearing of SVCLs ($p = 0.05$), LAMFCLs ($p = 0.32$) and the HAMFCLs ($p = 0.85$).

Because PRA and NRA mean results for pre and post-lens wear show no statistically significant differences after comparing using the paired sample t-test, the post-lens wear relative accommodation mean results were used to compare between the four test lens conditions to determine whether there were any significant differences between them by using the repeated measure ANOVA.

Statistically significant differences were found when comparing between the SPECT, SVCLs, LAMFCLs and HAMFCLs for the PRA, $F (2.23, 51.23) = 6.36$, $p < 0.01$, partial $n^2 = 0.22$ and the NRA, $F (3, 69) = 10.27$, $p < 0.01$, partial $n^2 = 0.31$. The results of the relative accommodation are shown in figures 26 and 27.

For the PRA, *post hoc* analysis using the Bonferroni correction shows that a significant difference was only found when comparing between the HAMFCLs to SPECT [-3.43 (SD 1.04) vs -2.88 (SD 0.95), $p < 0.01$] and SVCLs [-3.43 (SD 1.04) vs -2.81 (SD 1.01), $p = 0.03$]. There was no significant difference between the mean of the PRA when comparing between SPECT and SVCLs [-2.88 (SD 0.95) vs -2.81 (SD 1.01), $p = 1.00$] or SPECT with LAMFCLs [-2.88 (SD 0.95) vs -3.22 (SD 1.38), $p = 0.25$]. When comparing SVCLs to LAMFCLs, there was also no significant difference found [-2.81 (SD 1.01) vs -3.22 (SD 1.38), $p = 0.10$]. There was also no significant difference detected between mean of the PRA for LAMFCLs and HAMFCLs [-3.22 (SD 1.38) vs -3.43 (SD 1.04), $p = 1.00$].

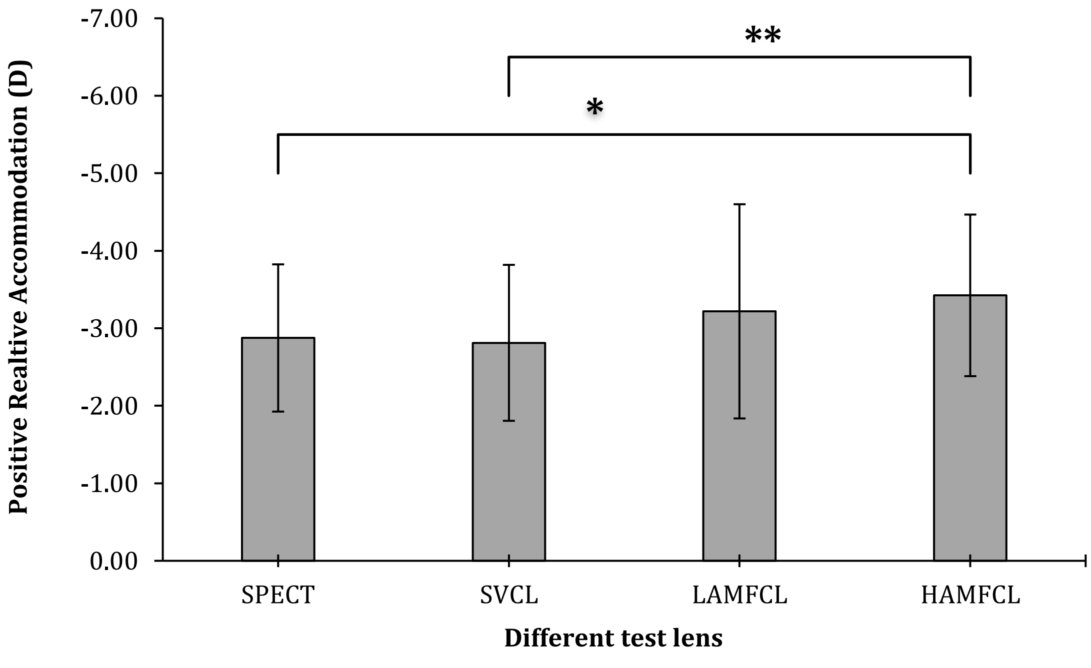


Figure 26. Bar chart representing the mean values of PRA for each test condition regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). A statistically significant difference was found between the mean PRA for the four test lens conditions ($p < 0.01$). A *Post hoc* test shows that a significant difference was found when comparing the mean PRA between HAMFCLs versus SPECT ($p < 0.01$) (indicated with *) and SVCLs ($p = 0.03$) (indicated with **).

For the NRA, *post hoc* analysis using the Bonferroni correction shows that significant differences were only found when comparing between the HAMFCLs to SPECT and SVCLs [2.52 (SD 0.49) vs 2.94 (SD 0.30) vs 3.00 (SD 0.55), respectively, $p < 0.01$]. There was no significant difference between the mean NRA when comparing between SPECT and SVCLs [2.94 (SD 0.30) vs 3.00 (SD 0.55), $p = 1.00$] or SPECT with LAMFCLs [2.94 (SD 0.30) vs 2.68 (SD 0.55), $p = 0.16$]. When comparing SVCLs to LAMFCLs, the result was slightly higher than the statistically significant level of 0.05, therefore it was still considered as no significant difference found [3.00 (SD 0.55) vs -2.68 (SD 0.55), $p = 0.06$]. There was also no significant difference detected between the mean of the NRA for LAMFCLs and HAMFCLs [2.68 (SD 0.55) vs 2.52 (SD 0.49), $p = 0.27$].

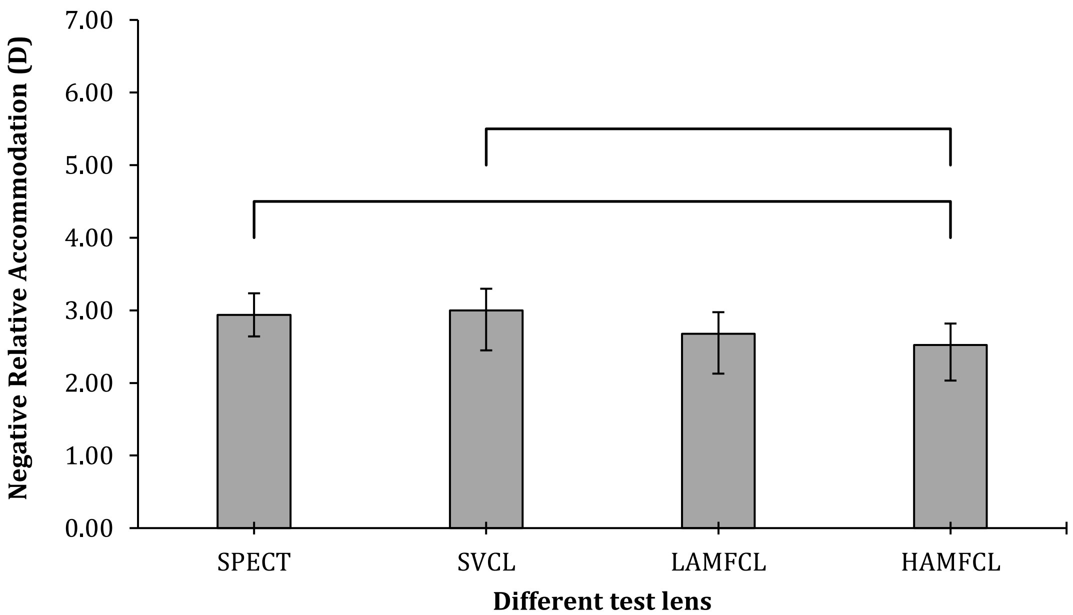


Figure 27. Bar chart representing the mean values of NRA for each test condition regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). A statistically significant difference was found between the mean NRA for the four test lens conditions ($p < 0.01$). A *Post hoc* test shows that a significant difference was found when comparing the mean NRA between HAMFCLs versus SPECT and SVCLs ($p < 0.01$).

The mean of the near point of convergence (NPC) for each test lens was also compared using the paired sample t-tests to determine whether there was any difference in the NPC between the pre and post wearing of each test lens. No significant differences were detected between the pre and post lens wear.

The mean NPC results for post lens wear were used to determine whether there was any statistically significant difference between each test lens condition by using the repeated measure ANOVA. A statistically significant difference was detected when comparing the NPC between the SPECT, SVCLs, LAMFCLs and HAMFCLs, $F (1.84, 42.42) = 14.59$, $p < 0.01$, partial $n^2 = 0.39$.

Post hoc analysis using the Bonferroni correction shows that significant differences were found between LAMFCLs versus SPECT and SVCLs [5.75 (SD 0.99) vs 8.08 (SD 2.45) vs 7.42 (SD 2.83), respectively, $p < 0.01$] and HAMFCLs versus Spect [6.08 (SD 1.14) vs 8.08 (SD 2.45), $p < 0.01$] and SVCLs [6.08 (SD 1.14) vs 7.42 (SD 2.83), $p = 0.01$]. There was no significant difference found between both LAMFCLs and HAMFCLs [5.75 (SD 0.99) vs 6.08 (SD 1.14), $p = 0.12$]. There was also no significant difference found between the SPECT and SVCLs [8.08 (SD 2.45) vs 7.42 (SD 2.83), $p = 0.07$].

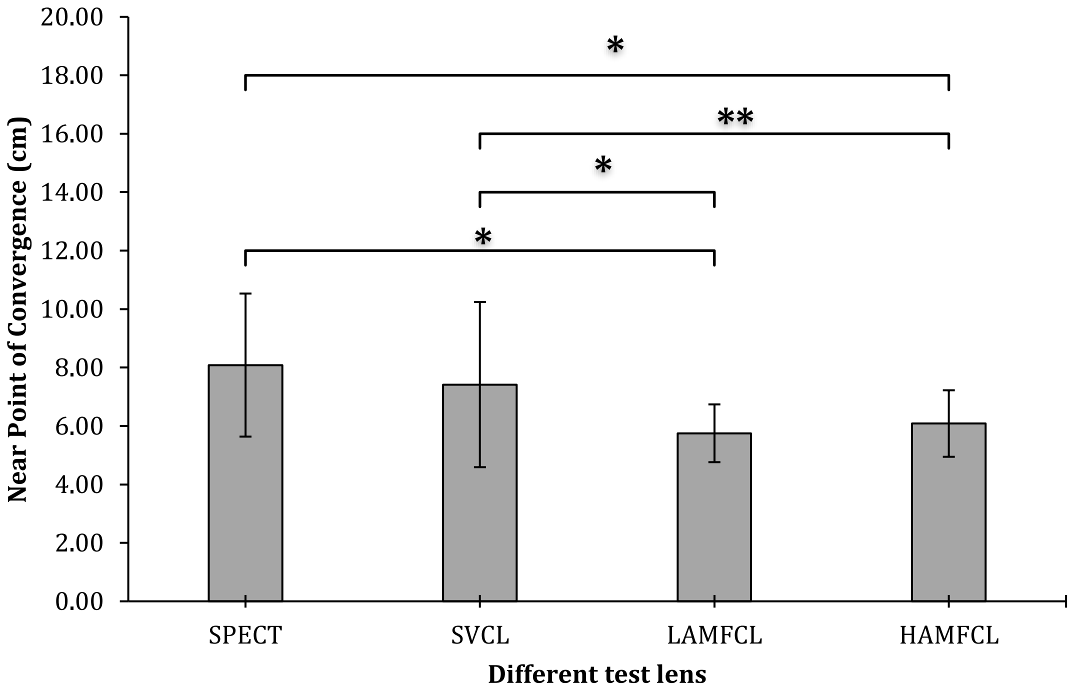


Figure 28. Bar chart representing the mean values of NPC for each test condition regardless of whether participants started with low or high add. Error bars represent ± one standard deviation (SD). A statistically significant difference was found between the mean NPC for the four test lens conditions ($p < 0.01$). A *Post hoc* test shows that a significant difference was found when comparing the mean NPC between LAMFCLs versus SPECT and SVCLs ($p < 0.01$) and HAMFCLs versus SPECT ($p < 0.01$) (indicated with *) and SVCLs ($p = 0.01$) (indicated with **).

4.5 Discussion

The present study demonstrates a statistically significant difference between the AoA finding of both eyes ($p < 0.01$) when comparing the results using SPECT and SVCLs wear to LAMFCLs and HAMFCLs wear. The AoA finding of the RE and LE was found to have increased when wearing LAMFCLs and HAMFCLs comparing to wearing either the SPECT or SVCLs; this shows that the accommodation response of pre-presbyopic individuals does exhibit changes with wearing of MFSCLs with centre-near design and that pre-presbyopes do utilise the near addition power of the MFSCLs. The finding of this study is similar to that of Gong et al. (2017) where accommodative response of their participants was affected by the MFSCLs but differed to finding of Pettersson et al. (2011), Madrid-Costa et al. (2011) and Kang and Wildsoet (2016), where no changes to the accommodative response of pre-presbyopic participants were found while wearing MFSCLs. The possible reason for the difference observed between this study's finding and the other three studies (Kang and Wildsoet, 2016; Madrid-Costa et al., 2011; Pettersson et al., 2011) might be because of the use of subjective clinical methods rather than objective methods.

As mentioned previously in section 4.1, previous studies using objective methods may have superior accuracy in accommodative measurement with MFSCLs wear. However, most of the studies (Gong et al., 2017; Madrid-Costa et al., 2011; Pettersson et al., 2011) rely on the results based on the consensual effect of the eyes to determine if there were any changes to the accommodative response. The reason for using consensual effect result was because of the power progression in MFSCLs, making it very difficult for the equipment to obtain a reliable measurement (Madrid-Costa et al., 2011; Pettersson et al., 2011).

The reason for using AoA measurement in this study was because it is a common clinical method used in optometric practice to determine the amount of accommodation. Besides that, quantitative measurement result can be obtained. With the results, it can be determined whether there is any improvement to the AoA measurement during MFSCLs wear, comparing to SPECT and SVCLs wear. Accommodative measurement can also be conducted with the actual MFSCLs on the eye, rather than using results based on the consensual effect of the eyes when measured using objective methods. During the AoA measurement, participants response can also be observed by the examiner, as the participants were constantly asked if the letter were clear when the target is progressively moved closer to the eyes. This method can provide more valuable clinical research outcome measurement comparing to objective methods.

In this study, the most common clinical method, the push-up technique, was used to evaluate the AoA (Wolffsohn et al., 2011; Burns et al., 2014). The possible reasons for the significant improvement in the AoA measurement with MFSCLs wear might be due to convergence accommodation (Heath, 1956) and pupil miosis (Von Noorden, 1985). As the fixation target moves toward the participant's eye along the mid-line of the face, even though one eye was occluded, it causes the eyes to naturally converge while focusing on the letters on the RAF rule. Due to the near triad function of the eyes, as the eyes converge, accommodation is triggered along with pupil miosis. With the possibility that additional pupil constriction occurs when viewing an object closer than the usual reading distance, the pupil may have constricted into the zone of higher addition power of the centre-near MFSCL: this resulted in utilising more of the near addition power at that particular close-up distance, therefore increasing the AoA finding.

As illustrated in section 2.6.2, Montés-Micó et al. (2014) reported that Air Optix Aqua MFSCLs have a centre-near zone of 3 mm and 3.6 mm diameter for the low add and high add, respectively. Therefore, if the participants pupil size during the close-up focusing of the near letters did constrict further and became smaller than the photopic pupil size that was measured, it would have moved further into the near zone and utilised more of the near add in the MFSCLs. In the results section, it can be observed that on average, there was an increase of 1.44 D and 1.60 D to the AoA measurement of the RE and an increase of 1.21 D and 1.36 D to the AoA measurement of the LE, while wearing the LAMFCLs and HAMFCLs as compared to the SVCLs.

One of the proven disadvantages of the push-up technique is that it may constantly give higher accommodative amplitude results as compared to objective methods (Rosenfield and Cohen, 1996; Wold et al., 2003; Wolffsohn et al., 2011). The higher AoA result obtained by this method is due to the eye's depth-of-focus, which increases due to accommodative pupil constriction, resulting in an overestimation of the result (Wold et al., 2003; Wolffsohn et al., 2011). However, the possibility that the difference in the results of this study was due to an overestimation of the AoA was not possible.

Firstly, the amount of AoA of all participants was collected using the subjective refraction results that were trial lenses on the participants during recruitment. The AoA was also measured on the first day participants were fitted with the SVCLs and followed by at the end of the month. The same method was used to collect the data for both the LAMFCLs and HAMFCLs. Therefore, if there was any overestimation of the AoA due to the test method, it would also have happened for both the SPECT and SVCL conditions, thereby cancelling out any form of over correction in the final result. With that, any form of improvement to the outcome measurement of the AoA detected during MFSCLs wear, would be a true increment and not because of overestimation in the result due to the test method.

Burns et al. (2014) also proposed that participant and the examiner reaction time maybe another source of error when using the push-up technique, which can result in higher AoA values. However, the possibility of this occurring in this study would also be very low because all participants were given a practice run on the push-up test technique before the study began. Therefore, over time, as the test was repeatedly conducted on each participant, they would already be mentally prepared on what they would be expected to do during the measurement of AoA and there would likely have been a learning effect occurring, which could only have improved the outcome of the test result. Additionally, with three readings taken and averaged, the approached further minimised the possibility of overestimation due to reaction time. Examiner and instrumentation error was also reduced, because only one optometrist (Alex Ong) conducted the test and used just one RAF rule for the entire study data collection.

Another possible reason for the increase in the AoA measurement observed in this study might also be due to spherical aberration (SA). As previously discussed in section 3.5, the amount of SA will change linearly with accommodation, from positive values during unaccommodated conditions towards more negative ones in the accommodated conditions (Wahlberg et al., 2011). The presence of SA, regardless of whether positive or negative, will increase the depth-of-focus (Bakaraju et al., 2010a).

The MFSCLs that were used in the study were all centre-near design and had been identified to induce negative primary SA (Fedtke et al., 2017). Therefore, while wearing centre-near MFSCLs, it might have created a larger ocular plus lens negative SA during accommodation at near. With higher negative SA, it indirectly increases the depth-of-focus (Bakaraju et al., 2010a; Fedtke et al., 2017), which may have resulted in a reduction to the perception of blur when the fixation letters were pushed up-close to the eye, thereby causing improvement to the AoA measurement observed in this study.

However, SA can be affected by the pupil aperture, with larger pupil size having a higher amount of SA induced (Bakaraju et al., 2010a; Bakaraju et al., 2010b; Zhu et al., 2015) and SA will approach zero when the pupil size is about 3.7 mm (Bakaraju et al, 2010b). The average photopic pupil size of normal young adults that was formerly reported ranged from a diameter of 2−4 mm (Spector, 1990). In this study, the average photopic pupil size of the participants was 3.96 mm (SD 0.57) for the RE and 4.00 mm (SD 0.61) for the LE (Table 4), which was consistent with data previously reported (Spector, 1990).

Because all the participants were Asian and had a dark coloured iris, measuring pupil size at the end point of the push-up test posed great difficulties and therefore, was not undertaken. However, there was the possibility that the pupil aperture might have decreased further during AoA measurement, resulting in the amount of SA created by the CL to be greatly reduced (Bakaraju et al, 2010b): therefore, negative SA might not have played a significant role in influencing the improvement of the AoA measurement observed in this study. With this consideration, the former explanation for the increased AoA finding has a stronger possibility than the latter. Alternatively, it might be a summation effect of both conditions that creates the improved AoA measurement observed in this study.

As previously discussed in Section 4.1 (see Table 6), Pettersson and co-workers' study (2011) assumed that the addition power of the MFSCLs in the RE would be able to relax the accommodation, creating a consensual effect in the LE. However, this might not be effective because of the participants' pupil size and the design of the MFSCL. According to the study, the participant average pupil size was 5.72 mm (SD 1.17) and the CL that was used in their study was centre-distance MFSCLs with an addition of +1.00 D. The centre-distance MFSCL has the addition power progressing only at a diameter of 2.3 mm onwards and only reaching the full addition power at 5 mm from the centre of the CL (Lopes-Ferreira et al., 2011; Pettersson et al., 2011). Therefore, some of the participant's pupil size might not be large enough to enter the maximum near addition zone and might be insufficient to relax the accommodation. Additionally, the +1.00 D near addition of the centre-distance MFSCL might not have been strong enough to create any significant relaxation to the eye's accommodation.

Furthermore, the amount of relaxation on the accommodation in the RE might not have provided the fellow eye with the optimum amount of consensual effect assumed. Charman and Koh (1997) reported that when one eye was stimulated with a minus lens to induce accommodation, the fellow eye does result in a significant increase in accommodation, but the changes were not equal to the stimulation. Therefore, it shows that the eyes might accommodate differently and the amount of near addition in the MFSCLs of the RE in Pettersson and colleagues' study (2011) might be insufficient to create a significant consensual relaxing effect to observe any form of accommodative response changes in the fellow eyes. Also, accommodative response measurements of the LE with the RE focusing on the near target, while using a septum to dissociate both eyes, would still have the LE be in a converging angle, which might possibly produce over or under-corrected spherical and cylindrical results (Whatham et al., 2009) because the objective measurement was not done on-axis to the centre of the eye, but slightly peripheral, thereby affecting the result.

Kang and Wildsoet (2016) conducted accommodation measurements under binocular condition using a COAS wavefront analyser, which provides a more natural objective measurement (Davies et al., 2003; Hunt et al., 2003; Wan et al., 2012). Similar to the study of Pettersson et al., centre-distance MFSCLs was used but with two different near addition powers: +1.50 D and +3.00 D. However, the pupil analysis diameter for the accommodative response while wearing MFSCLs was not determined. Lacking the pre-determined pupil diameter for accommodative analysis and the presence of power variation within the MFSCLs might have affected the final results in their study (Bakaraju et al., 2015; Madrid-Costa et al., 2011), resulting in no accommodative response change observed within their participants while wearing MFSCLs.

Madrid-Costa et al. (2011) used centre-near design MFSCLs with two near addition powers; low add (up to +1.50 D) and high add (+1.75 or greater), and tested the accommodative response at 25 cm and 40 cm. Although the MFSCLs used were similar to this study, the difference was that only two test distances were conducted, in which the pupil might not have constricted as much as in this study, when the letter target was pushed up-close until blurred. Indeed, the smallest pupil detected among their participants was 4.11 mm, whereas the average photopic pupil size in this study was 3.96 mm (SD 0.57) and 4.00 mm (SD 0.61) for the RE and LE, respectively (Table 4). Also, the pupil diameter reported in their study might not have been sufficiently small to enter the centre-near addition zone (Kim et al., 2017; Madrid-Costa et al., 2011), resulting in no accommodative response changes observed.

Furthermore, Kobashi and co-workers (2015) reported that during occlusion of one eye, the pupil size was larger as compared to when viewing binocularly; this effect might have affected the overall result in Madrid-Costa and co-workers' study because changes in pupil responses were used as an indicator for any accommodative changes. Additionally, monocular occlusion could result in poor focusing of the non-occluded eye and caused accommodation response to become unstable, thereby affecting the result obtained (Stark and Atchison, 2002).

The AoA of both eyes is usually similar and the accommodation amplitude should regress in the same speed (Scheimen and Wick, 2014). However, in this study, analyses of both the right and left eye was conducted. The rationale for including analyses of both eyes was to ensure that the baseline AoA of participants both eyes did not differ significantly. Also, when fitted with any CLs (e.g. SVCLs or MFSCLs), if the AoA measurement of the two eyes varies considerably during the eye examination, the examiner may need to consider whether the prescription of the CLs was correct. Because when the distant prescription is correctly prescribed, the AoA result of both eyes should not differ significantly. Also, if the AoA measurement of one eye was affected by the near addition of the MFSCL, a similar effect should also be detected in the fellow eye. Therefore, analyses of AoA outcome measurement findings for both the right and left eye would further ensure that an actual effect was indeed present and not due to any form of error.

NPC was also found to have statistically significant improvement (Figure 28). This improvement was observed when comparing both LAMFCLs and HAMFCLs to SPECT and SVCLs. These improvements in the NPC while wearing MFSCLs as compared to SPECT and SVCLs wear might suggest that pre-presbyopes participants in this study were utilising the near addition power of the centre-near MFSCLs, which resulted in delaying the blur observation, thereby allowing the test target to be able to push closer to the eyes. The possible reasons for the improvement in NPC observed might be similar to the reasons previously discussed regarding the improvement of AoA, because the NPC test was performed with the same RAF rule and using a similar test method. The only difference was that NPC was tested binocularly whereas AoA was tested monocularly.

Another possible reason for the improvement in NPC might be due to the near heterophoria changes with MFSCL wear. As observed in section 3.4 of this thesis and other studies (Gong et al., 2017; Hua et al., 2012; Kang and Wildsoet, 2016), near heterophoria shifted towards less esophoric with MFSCLs. The higher amount of near esophoria observed with SPECT and SVCLs means that the eyes converged more than both the LAMFCLs and HAMFCLs at the same viewing distance and therefore, required the use of a higher amount of NFV to maintain the clarity of the near target. If the amount of NFV was not sufficient enough to compensate for that particular distance, a lower NPC result would occur.

Improvement in the NPC could also be observed when comparing SPECT to SVCLs ($p = 0.07$). The slight improvement, although not statistically significant, may be due to the absence of the base-in prism during CL wear. When myopes converge to bi-fixate on a near object while wearing spectacles, the eyes will shift from the centre of the spectacle lenses, where there is zero prismatic effect, to the nasal part of the lenses and seeing through the base-in prism. Based on theory, it would reduce the amount of convergence required. However, base-in prisms can also cause an increased in NFV demand required (Scheiman and Wick, 2014) since all participants were either near esophoric or orthophoric. As the target moves closer to the participant, an increase in base-in prism was induced in each eye, requiring the eyes to increase their divergence ability to maintain clear binocular single vision; this might be the reason why NPC for SPECT was slightly lower than SVCLs wear.

The NPC result in this study was similar to Jiménez and co-workers' (2011) finding, where no differences were found in NPC value when comparing SPECT wearing to SVCLs. In their study, the spectacle lenses were adjusted to the near PD of their participants, thereby having no prismatic effect. In this study, no adjustment to the PD of the spectacle was made, to provide more valuable information about the NPC changes between SPECT and SVCL wear in real clinical conditions.

Relative accommodation of the eyes was also tested for all participants while wearing SPECT and all three types of CLs. In this study, relative accommodation was conducted to determine whether there were any changes to the accommodation response while wearing the centre-near MFSCLs when comparing to SVCLs and SPECT. If the accommodative response is affected, modification to the NRA and PRA value will be observed. When analysing the PRA result, it was found that the PRA value shows statistically significant increases when wearing HAMFCLs as compared to SPECT and SVCLs. Similarly, a statistically significant reduction in the NRA value was also observed when comparing the HAMFCLs to SPECT and SVCLs.

The PRA result while wearing HAMFCLs shows that there was an increase of -0.55 D and -0.61 D when compared to SPECT and SVCL, respectively. The result suggest that the participants were using the near addition power of the HAMFCLs while viewing the test letters at 40 cm, thereby allowing more minus power lenses to be added before blurring was noticed. NRA value was also significantly decreased when comparing the HAMFCLs to SPECT and SVCLs, with a difference of 0.42 D and 0.48 D, respectively. These reductions further support that there was a true modification to the PRA values because both NRA and PRA are inter-related (Scheiman and Wick, 2014), and further suggests that participants might be utilising the near addition power in the MFSCLs, because they were unable to accept the same amount of plus power that was formerly found with SPECT and SVCLs.

Evidence of accommodative response of pre-presbyopes being affected by the MFSCLs can also be seen from another perspective using the PRA and NRA test by interpreting using the fusional vergence results. The relative accommodation test is also an indirect test for PFV and NFV, where the PRA test is an indirect test for NFV while NRA is a test for PFV (Hinkley et al., 2014; Morgan, 1994a; Schieman and Wick, 2014) (see Section 2.3).

In the situation where the ocular condition present with near esophoria, there will be a decrease in the PRA finding, the reason being that the esophoric condition resulted in the eyes having a lower ability to diverge because it is in a more converging condition. In section 3.4 of this thesis, although the result was not statistically significant, the near heterophoria finding was observed to be slightly less esophoric while wearing MFSCLs versus SPECT and SVCLs at near. The reason for the slight exophoric shift, as discussed previously in section 3.5, might be either due to either the near addition power relaxing the accommodation or the presence of negative SA from the centre-near MFSCLs, which might have increased the depth-of-focus, resulting in a lessening need for accommodation and therefore, causing a shift in exophoric direction (Gong et al., 2017).

Due to the slight exophoric shift observed with MFSCLs in this study, SPECT and SVCLS would therefore be expected to have lower PRA and higher NRA when compared to both LAMFCLs and HAMFCLs. This assumption was found to be true because the result of the study did show that both PRA and NRA values had statistically significant differences found when comparing HAMFCLs to SPECT and SVCLs.

A slight increase in the PRA value was also observed in the LAMFCLs when comparing to SPECT and SVCLs. The amount of increase when comparing to SPECT and SVCLs was about -0.34 and -0.41, respectively. Similarly, reduction to the NRA value could also be seen when comparing the LAMFCLs to SPECT and SVCLs, where there was a reduction of 0.26 D and 0.32 D, respectively. These changes, although smaller than the result found with HAMFCLs and also not statistically significant, does indicate a similar trend of changes to the relative accommodation. The possible reason for the insignificant result in LAMFCLs may be due to insufficient pupil constriction of the participants' pupil to enter the zone of the higher addition power in the

LAMFCLs. It was reported by Montés-Micó et al. (2014) that a pupil size of at least 3 mm is necessary to start entering the near addition zone of LAMFCL and required smaller than 3 mm to advance into the higher near addition power in the centre of the CL. Comparing to the HAMFCLs design, a pupil size of 3.6 mm will be sufficient to enter the near addition zone (Montés-Micó et al., 2014), therefore this might have explained why HAMFCLs shows more significant changes to the relative accommodation result than LAMFCLs.

In Lee co-workers' study (2015), which uses the same MFSCLs as this study, a slight increase in PRA value and a decreased NRA value when comparing between LAMFCLs to SVCLs was also reported. To our knowledge, there has been no other study conducted to examine relative accommodation using HAMFCLs, and for this reason, it was not possible to compare our HAMFCLs result to other reports.

Madrid-Costa et al. (2011) proposed that it would be valuable to determine whether the accommodative response will be affected after wearing MFSCLs for a longer period of 1−6 months. The reason for the suggestion was based on a study by Montés-Mićo and Alió (2003), which reported that simultaneous image multifocal implants took approximately 3−6 months before contrast sensitivity reached maximum clarity and stability. Due to this observation, it was proposed that a learning process for simultaneous focusing was required. Fernandes et al. (2013) also reported that VA for both distance and near improved after 15 days of wearing MFSCLs, and indicated that an adaptation period is required.

As most of the studies (Gong et al., 2017; Kang et al., 2015; Kang and Wildsoet, 2016; Madrid-Costa et al., 2011; Pettersson et al., 2011) that analysed MFSCLs and accommodative responses were performed with less than one month of adaptation and with the understanding that a longer adaptation period might be required for MFSCLs to achieve its maximum clarity, the AoA and relative accommodation results of both LAMFCLs and HAMFCLs, collected on the first day of wearing (pre) and after one month (post) were analysed using paired sample t-tests.

No significant differences were observed in the AoA results for each eye after pre and post wearing of either the LAMFCLs or HAMFCLs for one month (Figures 21 and 23). Relative accommodation also shows no significant differences between the pre and post wearing for the LAMFCLs and HAMFCLs (Figures 25 and 26). The results suggested the absence of any form of learning effect, because there were no improvements to the AoA and relative accommodation detected after one month of MFSCL wear.

The limitation of this study was that all the participants were Asians and therefore had dark brown irises; therefore, it posed difficulties in measuring the pupil size without additional close-up lighting during the push-up test. However, with additional lighting close to the eye, it might cause further pupil constriction and provide false results of the actual pupil size at the end point during the measurement of the AoA.

In future work, the amount of pupil miosis at the end point of the push-up test could be determine by incorporating a similar method that was used by Cardona and Lópex (2016). In their study, a measuring scale was placed near to the eye and a digital photograph was taken; this will allow the actual pupil size to be measured clinically without the use of additional lighting. Alternatively, pupil size can be measured using an open-field auto-refractometer with the target distance adjusted according to the result obtained during the push-up test. However, most clinical settings might not have this equipment and also this study was designed to conduct the tests using common clinical methods to provide realistic clinical results for general optometric practice.

In this study, the PRA and NRA measurements were conducted at a test distance of 40 cm. The testing distance was based on the standard testing procedure recommended by Scheimen and Wick (2014). However, this might not be the habitual reading distance of the study participants. If relative accommodation was tested based on participants habitual reading distance, it might provide more realistic accommodative response information. By doing this, if more of the near addition was utilised while wearing MFSCLs at a shorter test distance, the finding of PRA and NRA will be different. Also, the possibility of a significant difference of relative accommodation finding between 40 cm and habitual testing distance can be determined. Therefore, future study should consider testing the relative accommodation at participants habitual reading distance.

Another improvement to future work that should be considered is the incorporation of an accommodative facility test to further determine whether there is indeed a change in accommodative response and binocular condition of the eyes while wearing MFSCLs. The facility of accommodation test measures the speed of accommodative responsiveness to blur by using flipper of negative and positive power lenses to induce and relax accommodation (Pandian et al., 2006). When conducting the test monocularly, should pre-presbyope accommodative response be affected by the near addition of MFSCLs, it would be difficult to maintain clarity of the near target when a plus power flipper lens is placed in front of the eye, resulting in a reduction in the test result when comparing to SVCLs. Similarly, when tested binocularly, if the MFSCLs did induce an exophoric shift to the near heterophoria, the eyes would be able to maintain clarity for the minus power flipper lenses more easily than the plus power flipper lenses due to a decrease to the PFV ability.

Furthermore, the adaptation period of the MFSCLs given to the participants might be too short to observe any form of learning effect from simultaneous focusing CLs. It can be observed in the paired sample t-tests results that both the PRA and NRA shows slight changes, with increases in the PRA value after one month of wearing LAMFCLs and HAMFCLs and a decrease in the NRA value slightly for the LAMFCLs. It would be interesting to see whether there would be any changes to the accommodative response after wearing the centre-near MFSCLs with the same addition powered for 3−6 months and giving them a washout period of one month before putting them over to other addition powered for another 3−6 months.

4.6 Conclusion

The finding in this study shows that when comparing SPECT and SVCLs to both centre-near LAMFCLs and HAMFCLs, the outcome measurement result of the AoA was improved with MFSCLs wear for both the RE and LE, suggesting that MFSCLs did affect the accommodative response of pre-presbyopes at near. The significant improvement to the NPC, when comparing both MFSCLs wear to SPECT and SVCLs, might also be an indirect indication that there was indeed an improvement to the measurement of the AoA when wearing MFSCLs. Alternatively, these improvements in results may be due to the extreme pupil miosis that might have occurred because of the closeness of the target that was shifted toward the participant's eyes along the midline of the face.

Relative accommodation tests showed an increased PRA and a decreased in the NRA value only for HAMFCLs. The changes in relative accommodation results might be another indication suggesting that accommodation response was affected by the MFSCLs at 40 cm test distance or it might be due to the slight exophoric shift observed in section 3.5.

No significant differences were found for all the test results between immediate and after one month of wearing the three different types of CLs, suggesting that there was no improvement to the accommodative response after one month of adaptation period. It would be beneficial to determine the effect of wearing centre-near MFSCLs for a longer period for pre-presbyopes, because this will provide more useful information for clinical use of MFSCLs on patients with either accommodative or binocular vision complications.

5.0 A Survey on the Methods of Detection and Management of Visual Fatigue among Singapore Optometrists.

5.1 Introduction

When performing a demanding visual task, a person commonly complains of discomfort in and around the eyes. Most people will term this condition as 'eyestrain' (Schapero and Hofsetter, 1968; Sheedy, 2007) but the actual medical term for this 'eyestrain' is known as 'asthenopia' (ICD-9 368.13) (International Classification of Diseases, 2002; Sheedy et al., 2003; Sheedy, 2007). Ocular asthenopia is a condition that can be caused by multiple conditions (Sheedy et al., 2003). Some of the possible conditions have been listed in section 2.5 of this thesis. Extended hours of near work have been identified as a major concern as one of the causes of asthenopic visual symptoms (Grisham et al., 1993; Owens and Wolf-Kelly, 1987). As reported by Murata et al. (1996), these symptoms may not be experienced immediately but will eventually surface over a period of time due to accumulation of the fatigue condition.

With the evolution in lifestyle, the demand and duration of near visual requirement has changed. The use of digital devices such as computers, tablets and smartphones for either vocational or recreational activities has become a part of day-to-day life globally (Rosenfield, 2011). Singapore was reported to have the highest Internet penetration rate in South East Asia (Digitalinfluencelabcom, 2015) with the amount of time spent on digital devices increasing. In 2015, Singaporeans spent about 3.2 hours a day on their mobile devices (Tnsglobalcom, 2015) and the amount of time spent had increased to 12 hours 42 minutes a day in 2017 (EY, n.d; Lin and Toh, 2017).

With the increase in usage time, great stress is placed on the accommodation and vergence systems, which may, in turn, result in ocular fatigue symptoms (Bababekova et al., 2011; Rosenfield, 2011). Rosenfield et al. (2011) highlighted that these varieties of symptoms experienced are classified as computer vision syndrome (CVS), which is defined by the American Optometric Association as the combination of eye and vision problems associated with the use of computers. Besides the long usage period at near, current digital devices vary in size and, therefore, the text size may also vary (i.e. with a smaller smartphone screen, the font size will also be smaller). Studies (Bababekova et al., 2011; Long et al., 2017) have also shown that the working distance with digital devices could be much shorter than when reading with printed material.

Even though high-intensity usage of digital devices and the substantial long hours of near visual tasks had been reported in Singapore, there was no report showing how frequently Singapore optometrists are seeing ocular fatigue patients and how they are being managed.

With the understanding that long hours of near visual demand may cause visual fatigue and with the lack of information on the prevalence and management of ocular fatigue by Singapore optometrists, the aim of this study was to conduct a survey with the Singapore optometrists regarding visual fatigue patients seen during their practising career.

The main objective of this survey is to have a better understanding of the following:

1. How do optometrists in Singapore detect visual fatigue symptoms among their patients?
2. What sort of treatment option(s) do Singapore optometrists engage in helping with visual fatigue conditions for their patients?
3. What is/are the success rate/s of the treatments given to their patients?

In addition to understanding the trend of diagnosis and treatment by the optometrists, the survey will also examine whether optometrists have ever considered using multifocal soft contact lenses (MFSCLs) as a treatment option for visual fatigue symptoms and the reason for their decision. This examination is particularly important in light of studies and reports indicating that MFSCLs are useful in some cases of accommodative and binocular vision treatment (Chu and Huang, 2010; Edmondson, 1985).

5.2 Methods and Material

The study was reviewed and approved by the Aston University Research Ethics Committee (AU REC) (see Appendix 2). The research protocol adhered to the tenets of the Declaration of Helsinki. All participants read the objective and confidentiality protection of this study before proceeding with the survey. There was no monetary benefit in taking part in this survey and all prospective participants had the right not to take part in this study (see Appendix 5).

5.2.1 Study Population

The survey was conducted between August 2016 to January of 2017. Participants were located from the list of registered optometrists obtained from the Singapore Optometrist and Optician Board website. Total of 1184 optometrists was found to have registered with the board (assessed on July 2016). All the registered optometrists were given the opportunity to participate in this survey. Participants were approached and recruited either by direct contact through a telephone call, social media (Facebook, Menlo Park, California, United States) or by requesting a referral from participants who have optometrist classmates. Participants were recruited from private practices, schools of optometry (institution), ophthalmologist clinics, government hospitals and any working environment that optometrists' work was engaged with (others).

5.2.2 Study Procedure

The questions to the questionnaire were constructed after discussion with Professor Leon Davies, supervisor of this thesis. After finalising the questions, the questionnaire was sent to an optometrist colleague in Ngee Ann Polytechnic to evaluate the relevance and validity of the questions. After receiving valuable feedback, the questionnaire was edited and approved by Professor Leon Davies before constructing into electronic questionnaire using the Google forms (see Appendix 6). A link to the Google form, comprising a total of 12 questions, was sent to the participants upon obtaining their consent.

The demographics of participants were determined by asking for their age and gender followed by asking:

- Their years of practising experience (Question 1) and,
- The type of practice setting they are currently working in (Question 2).

In order to understand how ocular fatigue was diagnosed, Question 3 asked whether the participants had ever encountered any ocular fatigue cases. All participants were required to respond either ‘*yes*’ or ‘*no*’ to the question. If the responses were ‘yes’, they would need to:

- Provide an estimation on the number of visual fatigue cases they encounter within a month (Question 4),
- List the type of symptom(s) that visual fatigue patients usually presented to them (Question5) and,
- Answer whether any questionnaire or form was used to determine the presence of visual fatigue and its severity by either ‘yes’ or ‘no’ (Question 6).

If the responses were ‘*yes*’ to Question 6, participants would need to proceed to Question 7, which asked about the type of optometric symptoms’ form that they regularly use. If they responded with ‘*no*’ to Question 6, they would skip Question 7 and proceed to answer Question 8.

Question 8 inquired whether any type of treatment(s) was provided to the visual fatigue cases that they diagnosed. If the response was '*yes*', they were required to:

- List the type of treatment they commonly prescribe (Question 9) and
- Rate the treatment success rate from a scale of one to five (Question 10).

If the participant answered '*no*' to Question 8, they will proceed to Question 11 and 12, which asked:

- Whether had they ever considered using MFSCLs as a treatment option for ocular fatigue patients by responding with either '*yes*' or '*no*' (Question 11) and,
- The reason(s) regarding their response to Question 11 (Question 12).

For participants who answered '*no*' to Question 3, they would proceed to answer only Questions 11 and 12.

Once completed, the participants would submit their responses by clicking the submit button at the bottom of the Google form. Results were consolidated into an Excel worksheet (Microsoft Excel 2016, Microsoft Corporation, Redmond, Washington), which only the administrator had access to.

5.2.3 Thematic Analysis

Unlike numeric data, qualitative data is often harder to analyse using statistical methods to produce meaningful and informative results. Thematic analysis is a method commonly used for identifying, analysing and reporting patterns found within qualitative data (Braun and Clarke, 2006). According to Braun and Clarke (2006), thematic analysis is poorly demarcated and rarely acknowledged, but it is a commonly used method for qualitative data analysis, with no clear agreement regarding what thematic analysis is and the way this analysis is conducted.

The process of thematic analysis, according to Braun and Clarke (2006), can be conducted in six phases and is described in Table 9 below.

Phase		Description of the process
1.	Familiarising yourself with your data:	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
2.	Generating initial codes:	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3.	Searching for themes:	Collating codes into potential themes, gathering all data relevant to each potential theme.
4.	Reviewing themes:	Checking whether the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
5.	Defining and naming themes:	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6.	Producing the report:	The final opportunity for analysis. Selection of vivid, compelling extract examples, the final analysis of selected extracts, relating back the analysis to the research question and literature, producing a scholarly report of the analysis.

Table 9: Description of the phases and processes of conducting the thematic analysis. A total of six phases and processes are summarised in the table.

In this study, qualitative data were analysed using the thematic analysis method (Braun and Clarke, 2006). To conduct thematic analysis of question 12 responses, the researcher first read all the comments to become familiar with the data and to gather ideas on common themes. Responses were read a number of times to note down ideas for coding required for the next few phases. Once familiarised with the data and having a list of generated ideas, the process of coding was carried out. Codes were used to identify certain features of the data, which were of interest to the researcher. Table 10 shows examples of how data was being extracted with codes applied to respondents' comments. After the coding process was completed, the researcher analysed all the codes and created themes that were revised and refined into final themes, which are explained in the following sections (Braun and Clarke, 2006).

Data Extracts	**Coded As**
There was no specific teaching in school about these lens able to work on ocular fatigue patients and also, no lens company have any research on it.	1. No experience 2. Lack of scientific proof
Fatigue complains usually comes together with dryness. Contact lens may worsen dryness issues	1. Dryness with contact

Table 10: An example of data extraction from the participants' responses and thematic codes applied.

The following themes were identified for the respondents who did not consider MFSCLs as a treatment option: lack of scientific evidence, awareness and experience, side effects, CL wearer and alternative method, poor visual quality, and costing and limitation. The following themes were identified for the respondents who consider MFSCLs as a treatment option: effectiveness of lenses, CL wearer, cosmetic reason, younger patient and personal experience.

As qualitative data analysis involved interpreting the study findings, it can be argued that the results are strongly based on the researcher's subjective interpretation and may not be as reliable compared to quantitative analysis (Pope et al., 1999). In order to validate the results and decrease bias, one of the ways is to have the results validated by another person experienced in thematic data analysis. For this study, the validation process involved an experienced researcher independently reviewing the data and processing the codes and themes, thereby reducing the possibility of bias from one person's opinion and also strengthening the insights into the themes and data interpretation (Pope et al., 1999; Barbour, 2001).

5.3 Statistical Methods

Participants' demographic analysis was conducted by determining the mean age of all participants. The mean age was also determined for the gender differences recruited for the study. The number of visual fatigue cases attended within a month (Question 4) was first consolidated and then averaged. All mean results in this study were determined using the mean function of IBM SPSS statistics 23 (IBM Corporation, Armonk, New York). The software was used to generate the minimum, maximum and range of participants' age and visual fatigue cases.

For questions that participants responded from a list of selected answers:

- The years of practicing experience (Question 1),
- The type of practice setting (Question 2),
- Whether had the participants had ever encountered any ocular fatigue cases (Question 3),
- Whether any optometric form was used to determine the presence and severity of ocular fatigue (Question 6),
- The type of questionnaire or form used (Question 7),
- Whether treatment(s) was given to ocular fatigue patients (Question 8),
- The success rate for the treatment options (Question 10) and,
- The consideration of using MFSCLs as a treatment option for visual fatigue (Question 11)

The responses for each question were consolidated and tabulated into number and percentage.

The type of symptoms that visual fatigue patients presented (Question 5) and the type of treatments prescribed (Question 9), that were responded by the participants, were first collected, analysed and categorised into different categories. The frequency (f) of the symptoms and treatments responded were then consolidated with the most common to the least common type of symptoms and treatments determined.

The detailed replies from all the participants regarding their concerns on the use of MFSCLs as a treatment option for visual fatigue (Question 12), were divided into two categories: The reason for considering and not considering the use of MFSCLs for treating visual fatigue. These responses were further analysed using thematic analysis, a qualitative method used for '*identifying, analysing and reporting patterns (themes) within data'* (Braun and Clarke, 2006). Each participant's response was analysed, and a coding framework was generated, which was reviewed by two people. Themes were then created based on the code generated. Once completed, the code was allocated and consolidated into each theme and the number of codes allocated into each particular theme was calculated and reported (f).

Data were mined with the aid of the Excel worksheet table and chart function (Microsoft Excel 2016, Microsoft Corporation, Redmond, Washington). Data were stored using the same Excel software.

5.4 Result

Participant Demographics

A total of 100 survey response, about 10 percent of the total number of registered optometrists in Singapore, was collected. Participants consisting of 38 males and 62 females, with a mean age of 31.87 years (SD 8.22) and age range from 22−54 years. The mean age of the male participants was 34.82 years (SD 8.73) (range from 23 to 54), and the mean age of the female participants was 30.06 years (SD 7.39) (range from 22 to 52) (Table 11). 30% of the participants had practising experience of 1−5 years, 24% had 6−10 years' experience, 28% had 11−15 years' experience, 11% had 16−20 years' experience and 7% had more than 21 years' experience (Figure 29).

	Mean (N)	SD	Min	Max	Range
All Participants	31.87 (100)	8.22	22	54	32
Male	34.82 (38)	8.73	23	54	31
Female	30.06 (62)	7.39	22	52	30

Table 11: Table showing the number of participants (N) and the mean age of all participants with standard deviation (SD). The minimum (Min), maximum (Max) and the range of age of the participants were also reported. The table also shows the breakdown of the mean age of all participants with standard deviation (SD), the minimum (Min), maximum (Max) and the range of age of the participants according to their gender and the number of participants in each gender group.

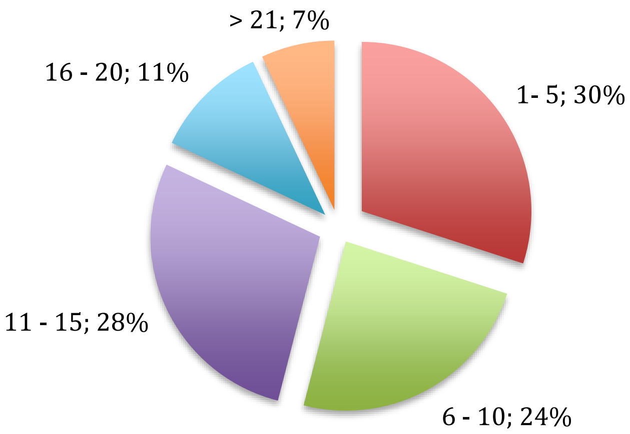


Figure 29: Pie chart indicating the years of experience of the participants taking part in the survey. 30% responded 1–5 years' experience, 24% responded 6–10 years' experience, 28% responded 11–15 years' experience, 11% responded 16–20 years' experience and 7% responded >21 years' experience.

In terms of mode of practice, 52% were in private practice, 13% were from the hospital, 11% from ophthalmologist clinics 13% from the institution and 11% from other sectors such as ophthalmic and contact lens manufacturers, multinational companies and medical device research and development departments (Figure 30).

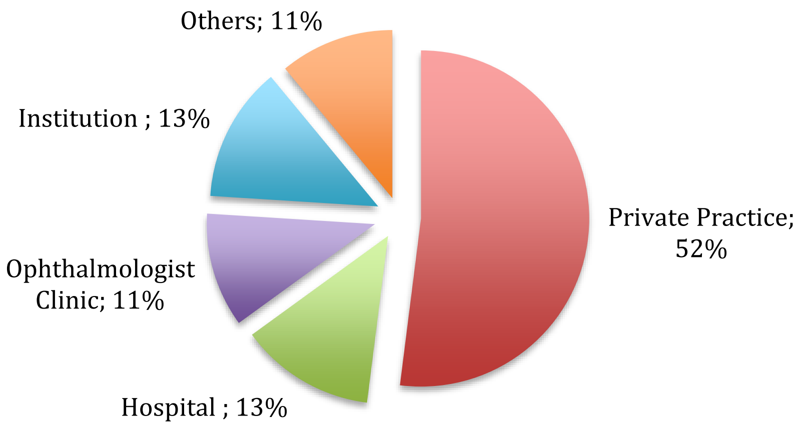


Figure 30: Pie chart indicating type of practice of all participants taking part in the survey. 52% responded Private Practice, 13% responded Hospital, 11% responded Ophthalmic Clinic, 13% responded Institution, 11% responded Others.

Diagnosis of Ocular Fatigue

In this study, 75% (N=75) of respondents noted that they do encounter ocular fatigue patients while 25% (N=25) replied that they do not encounter any ocular fatigue patients (Figure 31). Among these 75% of respondents, on average, 8.97 (SD 9.80) ocular fatigue cases were diagnosed in each month, with a range from 1 to 50 patients being diagnosed (Table 12).

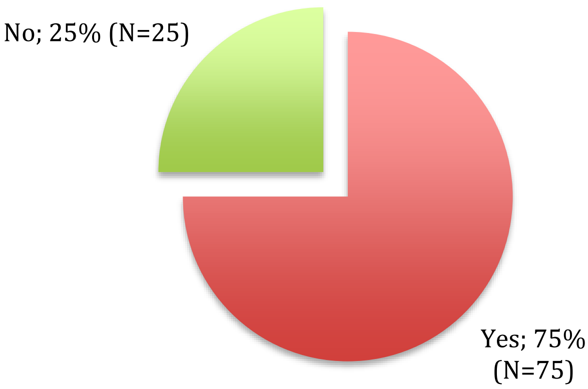


Figure 31: Pie chart showing the number of participants (N=100) who responded whether do they encounter any ocular fatigue patients during their course of practice. 75% (N=75) responded 'Yes', 25% (N=25) responded 'No'.

N	Mean (N)	SD	Min	Max	Range
75	8.97	9.80	1	50	49

Table 12: Table showing the mean number of ocular fatigue patients that were diagnosed in a month by 75% (N=75) of the respondents who reported encountering ocular fatigue patients, including the standard deviation (SD). The minimum (Min) and maximum (Max) number of ocular fatigue cases and its range are also shown.

Respondents who reported that they do come across ocular fatigue cases (75%) noted that symptom of tired eyes was most commonly reported (f=45). The second most commonly reported symptoms were blurred near vision (f=42), followed by headache or migraine (f=41) and blurred distance vision (f=28). Other less commonly reported symptoms include dry eyes (f=17), eye pain or aches (f=13) and diplopia (f=3) (Figure 32).

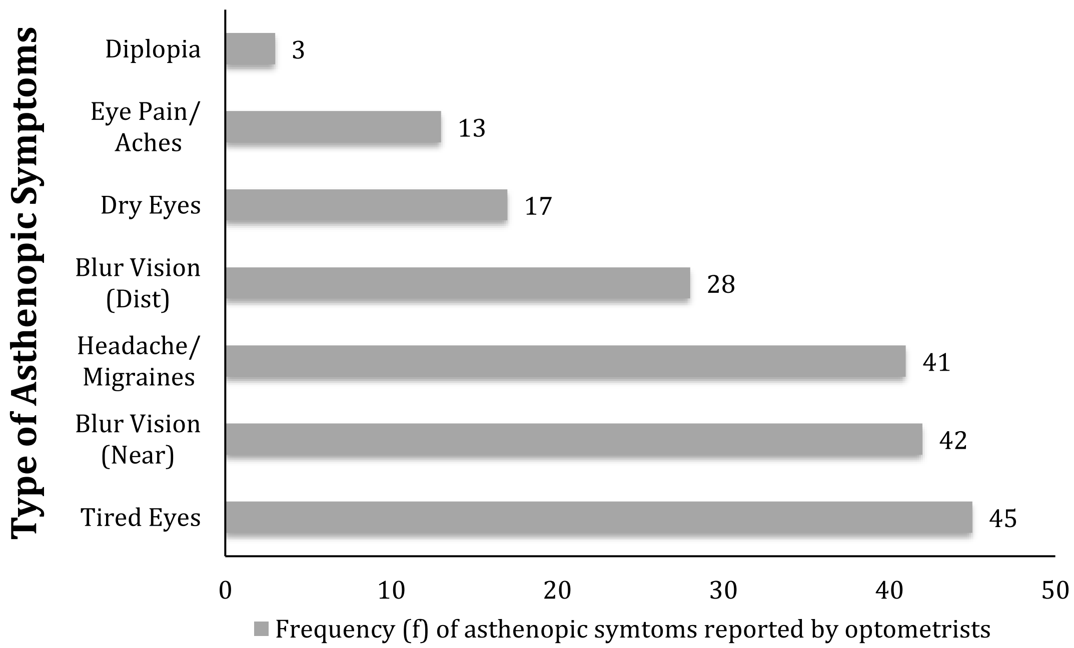


Figure 32: Bar chart showing the type of ocular fatigue symptoms most commonly presented during the eye examination and the frequency (f) of the symptoms reported. The results in the chart were arranged via having the less commonly reported symptoms (top) to the most commonly reported symptoms (bottom).

It was also found that within the 75% of respondents that were seeing ocular fatigue cases, only 9% (N=7) responded that they do utilise optometric forms to determine the presence of ocular fatigue and its severity, while 91% (N=68) responded that they do not (Figure 33). Among the 9% (N=7) of respondents who do use optometric forms, 43% (N=3) responded using the convergence insufficiency symptom survey form (CISS), 14% (N=1) used the shorter college of optometrists in vision development quality of life assessment (COVD-QOL) forms, while 43% (N=3) responded that they used other types of forms, which was indicated as an in-house developed symptom survey form. None of the respondents used the COVD questionnaire forms (Figure 34).

Figure 33: Pie chart showing 75% of respondents (N=75) who encounter ocular fatigue cases responded whether do they use any type of questionnaire or forms to determine the presence and severity of patients' ocular fatigue. 9% (N=7) responded 'Yes', 91% (N=68) responded 'No'.

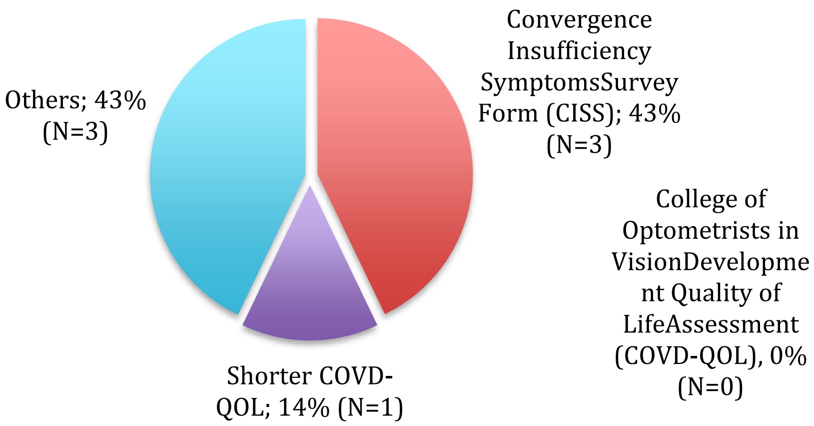


Figure 34: Pie chart showing the number of respondents (N=7) who responded to what type of questionnaire or forms they utilise to determine the presence and severity of patient ocular fatigue. 43% (N=3) responded the use of Convergence Insufficiency Symptoms Survey Form (CISS). 14% (N=1) responded the use of Shorter College of Optometrists in Vision Development Quality of Life assessment (COVD-QOL). 43% (N=3) responded using other type of forms, which are self-developed. No respondent reported the use of COVD-QOL forms.

Treatment of Ocular Fatigue

When 75% of respondents who do see cases of ocular fatigue were asked whether any treatment was provided, 83% (N=62) responded that they do provide treatment options, while 17% (N=13) replied that they do not (Figure 35).

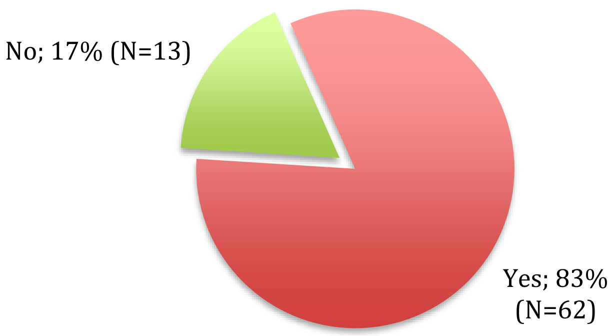


Figure 35: Pie chart showing the number of respondents (N=75) who responded whether do they provide treatment for their patients' ocular fatigue. 83% (N=62) responded 'Yes', 17% (N=13) responded 'No'.

According to the respondents (83%) who provided treatment options, it was found that the most commonly prescribed treatment was enhanced single vision lenses (ESVLs) (f=37). Progressive addition lenses (PALs) (f=26) was the second most commonly prescribed treatment followed by single vision near (SVN) lenses (f=24), visual therapy (VT) (f=12) and visual breaks (VB) (f=10). The less commonly prescribed treatments for ocular fatigue symptoms was blue light filter (BLF) coating ophthalmic lens (f=6), reducing myopic prescription for spectacle correction (f=6) and eye drops (f=3). Under the category of others (f=4), it consists of responses such as spectacle and anti-strain eyewear (Figure 36). Among the same group of respondents, it was also reported that 8% (N=5) felt that the treatment prescribed had a success rating of 5, while 64% (N=40) responded with a rating of 4, 26% (N=16) responded with a rating of 3 and 2% (N=1) responded with a rating of 2. None of the participants responded with a rating of 1.

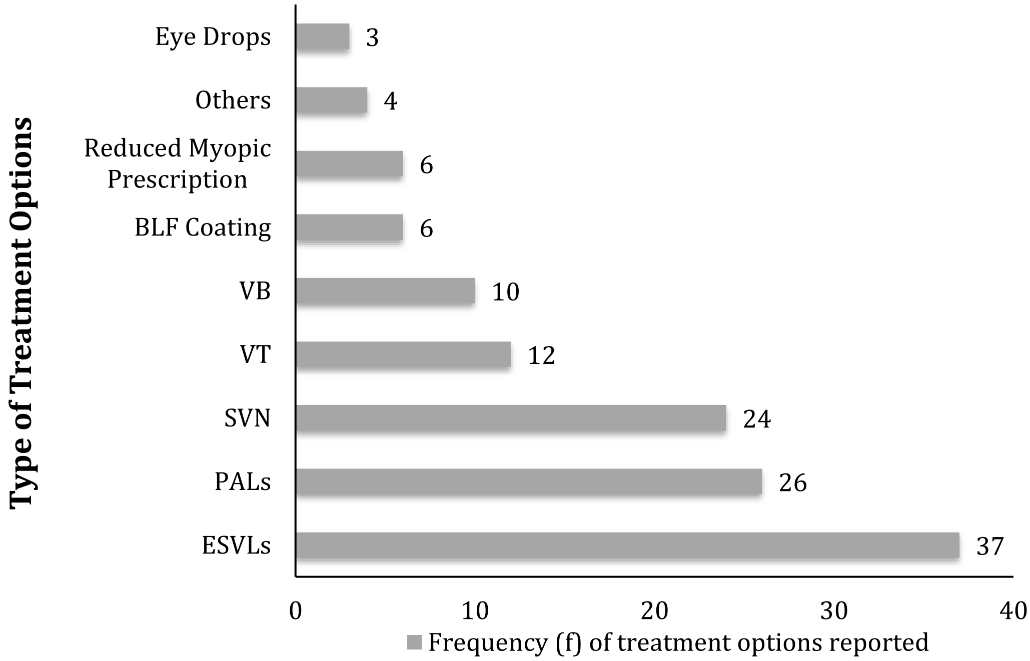


Figure 36: Bar chart showing the type of treatment options prescribed to ocular fatigue symptoms patients and the frequency (f) that the type of treatment was responded. The results in the chart were arranged via having the less commonly reported treatment prescribed (top) to the most commonly prescribed treatment (bottom).

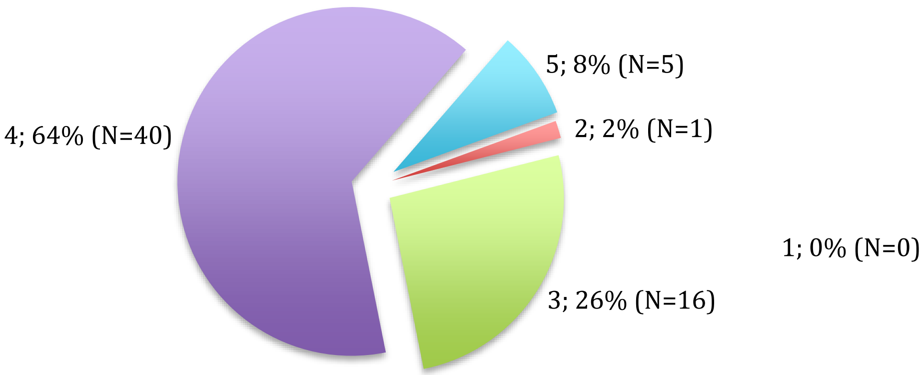


Figure 37: Pie chart showing the number of respondents (N=62) who responded to how successful the treatment(s) that they prescribed to ocular fatigue patients were. 8% (N=5) responded with a rating of 5, 64% (N=40) responded with a rating of 4, 35% (N=16) responded with a rating of 3, 2% (N=1) responded with a rating of 2, while none responded to a rating of 1.

MFSCLs as a Treatment Option for Ocular Fatigue

In this study, all the 100 participants were required to respond as to whether had they ever considered using MFSCLs as a treatment option for ocular fatigue patients. 69% (N=69) had not considered the use of MFSCLs as a treatment option while 31% (N=31) responded that they had (Figure 38).

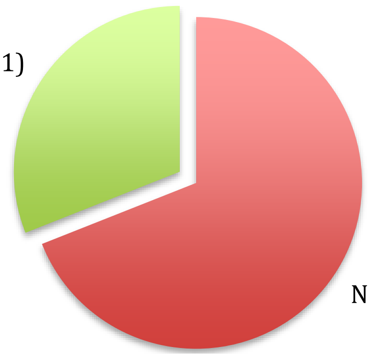


Figure 38: Pie chart showing the number of participants (N=100) who responded whether they have considered the use of MFSCL as a treatment options for ocular fatigue patients. 31% (N=31) responded 'Yes', 69% (N=69) responded 'No'.

The main reason for not considering the use of MFSCLs as a treatment option for ocular fatigue patients was the *lack of scientific evidence* showing the effectiveness of using MFSCLs as treatment options (f=37). This theme consisted of the responses coded such as: lack of evidence, not confident, and young age. *Lack of awareness and experience* with fitting MFSCLs was the second most common reasons (f=21), with responses consisting of either that they did not know, did not think of using MFSCLs or have no experience with fitting MFSCLs. Another identified theme was possible side effects that arise from wearing MFSCLs (f=11), such as dry eyes or increasing the amount of fatigue. The use of MFSCLs for *current CL wearers and the use of alternative methods* for treating asthenopic conditions (f=10) were also identified as the reasons for not considering MFSCLs.

Another identified theme was *poor visual quality for both distant and near vision* that might result from the use of MFSCLs (f=9). *Costing and limitation* (f=4) was the less common theme for not prescribing MFSCLs for asthenopic conditions, although two participants considered the use of MFSCLs to be more expensive comparing to other treatment methods and the other two participants responded that the lens parameters are limited (Table 13).

Theme	Total no. of responses (f)	Codes	No. of responses for each code
Lack of Scientific Evidence	37	Lack of Evidence	21
		Not Confident	14
		Young Age	2
Awareness & Experience	21	Did Not Know	5
		Did Not Think Of	6
		No Experience	10
Side Effects	11	Dry Eye	3
		Increase Fatigue	8
CL Wearer & Alternative Method	10	For Contact Lens Wearer	5
		Alternate Method	5
Poor Visual Quality	9	Unsatisfactory Vision	10
Costing & Limitation	4	High Cost	2
		Limited Parameters	2

Table 13: Table showing the themes for not considering fitting MFSCLs as a treatment option for ocular fatigue patients based on the descriptive data from our study respondents and the total number of times the reason was responded (f), which was consolidated based on the number of codes created from interpreting the descriptive data. The results in the chart are arranged via having the most commonly reported consideration (top) to the less commonly considered reason for not fitting MFSCLs for asthenopic patients (bottom).

For respondents who do consider using MFSCLs as a treatment option for ocular fatigue, the most commonly reported reason was *the effectiveness of lenses* (f=13), whereby the respondents felt that MFSCLs could reduce strain at near, relax the eye, reduce accommodation and are beneficial for ocular asthenopic conditions. The second most common reported reason was the benefits for *existing CL wearers* (f=8). Another identified theme included *cosmetic reasons* such as the convenience of wearing CL and patients' dislike of wearing spectacles (f=8). Some of the respondents also responded that younger patients who are pre-presbyopic would be another reason for their choice of fitting MFSCLs (f=3). The least common theme for considering the use of MFSCLs was based on personal experience with wearing MFSCLs by the study participant themselves (f=2) (Table 14).

Theme	**Total no. of responses (f)**	**Codes**	**No. of responses for each code**
Effectiveness of Lenses	13	Reduce Strain at Near	5
		Relax the Eyes	2
		Reduce Accommodation	4
		Beneficial	2
CL Wearer	8	For Contact Lens Wearer	8
Cosmetic Reason	8	Convenience	2
		Dislike Spectacles	6
MFSCLs for Younger Patients	3	Pre-Presbyopic	1
		Young age	2
Personal Experience	2	Personal Experience	2

Table 14: Table showing the themes for considering fitting MFSCLs as a treatment option for ocular fatigue patients based on the descriptive data from our study respondents and the total number of times the reason was responded (f), which was consolidated based on the number of codes created from interpreting the descriptive data. The results in the chart are arranged via having the most commonly reported consideration (top) to the less commonly considered reason for fitting MFSCLs for asthenopic patients (bottom).

5.5 Discussion

5.5.1 Demographic and Diagnosis of Asthenopia

The present study is the first to investigate the diagnosis and management of ocular fatigue by Singapore optometrists and leads to a better understanding of the concern regarding the use of MFSCLs as a treatment option.

In this study, 70% of participants had between 6−21 years of practicing experience. With longer practicing experiences, it would greatly increase the probability of the practitioners encountering asthenopic patients; therefore, the information gathered would be beneficial to this study and would be considered substantial in understanding the frequency of diagnosing and the management of asthenopic conditions in Singapore.

More than half of the total participants in this study were practicing in private practice (52%). The other 48% were spread across optometric settings such as hospitals, ophthalmologist clinics, institutions and other parts of the eye care industry in Singapore such as the manufacturing sector, which consists of ophthalmic lenses, CLs, research and development departments, etc. The distribution of the participants' practice setting was quite well spread and covers almost all of the possible optometric practising opportunities in Singapore. Therefore, this study will be able to provide a reliable insight regarding the diagnosing and management of asthenopic patients in Singapore.

Regardless of the type of practice setting, 75% of participants responded that they encounter asthenopic patients during their practicing career, with an average of 8.97 (SD 9.80) asthenopic symptomatic patients seen in each month. Data on the estimated total number of patients seen in each month from each participant's practice was not requested and furthermore, the prevalence of asthenopia in Singapore is currently unavailable, because no study has been conducted prior to this study; therefore, it was not possible to determine whether the amount of asthenopic patients seen by our participants was significant or not. In fact, studies undertaken to determine the prevalence of asthenopia are generally uncommon. Studies that were conducted shows variation in the results, likely due to several factors such as the population recruited in the study, sample size, methods of assessing asthenopic condition, the definition of asthenopia used in the study, etc. (Hashemi et al., 2017; Ostrovsky et al., 2012; Vilela et al, 2015), resulting in the actual information on the prevalence of asthenopia being non conclusive.

A systematic literature review by Vilela et al. (2015a) reported that the prevalence of asthenopia was 40.4% in adult professional computer users and 19.7% in children under the age of 18 years. The prevalence of asthenopia in Australian, Swedish and Indian school children was also shown in the review to range from 12.6% to 32.2% (Vilela et al., 2015a). Another report by Han et al. (2013) showed that the prevalence of asthenopia in Chinese students was 57%, while Hashemi et al. (2017) reported that 50% of the 1040 high school children with a mean age of 15.1 (SD 1.60) exhibit symptoms of asthenopia with 9.1% having four symptoms or more.

Nonetheless, due to the scarcity of the studies on asthenopia and the variation of the results and study methods, determination of the actual prevalence of asthenopia was difficult.

Nevertheless, by observing the studies mentioned above, it does show that asthenopia conditions can be commonly seen and the probability of asthenopia seems to be increasing with age (Hashemi et al., 2017). The reason for this higher prevalence might be due to the increased amount of near work and the usage of digital devices such as computers, smartphones and tablets (Hashemi et al., 2017; Ostrobsky et al., 2012; Vilela et al, 2015a; Vilela et al., 2015b). Besides that, the viewing distance of digital devices could be much closer than for printed material (Bababekova et al., 2011; Long et al., 2017; Rosenfield, 2011; Rosenfield, 2016) and prolonged viewing may stress the accommodation and extraocular muscle (Meister, 2016; Rosenfield, 2016). Some authors propose that the prevalence of asthenopia would likely increase due to the exposure to digital devices and computers at a much younger age, which may affect the children's academic learning (Hashemi et al., 2017; Vilela et al., 2015a; Vilela et al, 2015b).

The possibility of result variation may also have occurred in this study because it can be observed that the range of asthenopic patients encountered by all participants was 49, indicating relatively significant differences between participants. The reasons for the big range differences might be due to factors such as definition and the diagnostic methods used.

Because asthenopia can be caused by multiple conditions (Han et al., 2013; Sheedy et al., 2003), patients may, therefore, present with several different subjective symptoms of ocular discomfort. These symptoms of asthenopia usually include eyestrain, eye fatigue, discomfort, burning, irritation, pain, aches, sore eyes, tired eyes, headaches, photophobia, blur, double vision, itching, tearing, dryness and foreign-body sensation (Han et al., 2013; Sheedy et al., 2003). During a prospective study, asthenopia was further classified into two distinct types: internal and external symptoms (Sheedy et al., 2003). The external symptoms were deduced based on the sensations and location of the symptoms from the participants in the study, which the author was certain that these symptoms are related to irritation of the corneal surface secondary to dry eyes. The internal symptoms were proposed as any conditions that stress the visual functions of accommodation and ocular convergence because the symptoms' location are behind the eye and are close to the area of the oculomotor and ciliary muscles that are responsible for binocular alignment.

As observed in this study, the most commonly reported asthenopic symptom was tired eyes, followed by blurred vision at near, headaches or migraine and blurred vision at distance. The least-most-reported symptom was diplopia (Figure 32). Studies by Dwyer et al. (2015), McKay et al. (2002) and Westman et al. (2012) also show that the most commonly reported asthenopic symptoms were blurred vision at near, eye strain and tired eyes, which was similar to our study's finding.

Headaches was the most commonly reported asthenopic symptom, followed by itching and tearing, reported by Wajuihian et al. (2015). Other studies by Mvitu et al. (2003), Neugebauer et al. (1992) and Alexander et al. (1985) had also reported that headaches was the most common symptom of asthenopia. Albeit not being the highest reported symptoms in this study, headache and migraine had a relatively high report rate (t=41), which was rather close to symptoms of tired eyes and blurred vision at near, showing that this could potentially be one of the common chief complaints that resulted in patients seeking optometrist consults. Diplopia was the least common symptom reported by Wajuhian et al. (2015), which was the same as the finding in this study, showing that it was indeed not a very commonly encountered asthenopic symptom.

Although the majority (75%) of participants responded that they do encounter with asthenopic patients, only 9% responded that forms such as CISS, shorter COVD-QOL or in-house created symptoms survey forms were used to determine the presence and severity of asthenopia. This study result was quite interesting because it was known that the presence and severity of asthenopia cannot be objectively or clinically measured by standard optometric testing (e.g. retinoscopy or binocular vision test) (Ostrovsky et al., 2012). Also, an individual may have more than one type of symptom during a standard optometric consult (Hashemi et al., 2017). Therefore, without an appropriate optometric symptoms questionnaire being incorporated, it would be difficult to determine the severity of the symptom at the point of diagnosis, and it would not be possible to determine the effectiveness of the treatment prescribed because a comparison to the symptom score was not possible.

5.5.2 Management of Asthenopia

Among the 75% of the study participants who encounter asthenopic patients, 83% responded that they do prescribe treatments to asthenopic patients. The reason for not offering any treatment by the 17% of the participants was unknown, as they were not required to provide any answer in the study survey. Among the type of treatment prescribed, ESVLs was the most commonly utilised form of treatment, followed by PALs and SVN lenses. The least prescribed treatment was eye drops (Figure 36).

ESVLs contain a small amount of near addition at the lower portion of the lens, ranging from +0.50 D to +1.25 D, which is very similar in design to PALs, but with lesser peripheral blur (Meister, 2016). These lenses were introduced close to a decade ago, with Essilor launching its anti-fatigue™ lenses in 2009 (Essilor Visual Fatigue Solution, n.d), followed by Zeiss Digital lenses in 2014 (Zeiss Digital Lenses, n.d) and subsequently the replacement of Essilor anti-fatigue™ lenses with Eyezen™ in 2015. There were three proposed concepts for the development of such lenses. The main concept was based on the theory that during near work, accommodative function decreased after long hours, resulted in a reduction of the amplitude of accommodation (AoA) affecting the facility of accommodation, causing symptoms of temporary blur distance vision after near work (Sheedy and Shaw-McMinn, 2003). Therefore, the presence of a small amount of near addition in the lens will alleviate the load on accommodation, thereby decreasing the symptoms resulting from reduced accommodative facility.

The second concept was based on the understanding that the demand for sustained concentration during near work caused the mechanism of convergence to localise closer to the body than the mechanism of accommodation, thereby resulting in a mismatch between the accommodation and convergence systems. This mismatch can interfere with the visual efficiency and comprehension, resulting in asthenopia and impairing the ability to maintain near vision (Brinbaum, 2008; Meister, 2016). With the low plus power over the distance power, it can realign the over convergence during near work, thereby reducing the mismatch between the system.

The presence of the lag of accommodation at near in most individuals, especially for myopes (Gwiazda et al., 1993; Gwiazda et al., 2004; Gwiazda et al., 2005; Koomsoon et al., 2015; Koomson et al., 2016; McBrien and Millodot, 1986; Nakatsuka et al., 2005), may cause asthenopic symptoms (Brinbaum, 2008; Chase et al., 2009). Therefore, the use of marginal near addition power in ESVLs can reduce the amount of accommodative lag (Bao et al., 2013; Gwiazda et al., 2004; Koomson et al., 2015; Koomson et al., 2016; Rosenfield and Carrel, 2001), thereby reducing the symptoms of asthenopia, which provided the third concept for the use of ESVLs. However, the effect of ESVLs in alleviating asthenopic symptoms was not widely tested.

The effect of Essilor anti-fatigue™ lenses to reduce ocular fatigue was studied by Lee (2011), and it was reported that there was a statistically significant reduction in symptoms scores observed after wearing the anti-fatigue™ lenses. Even though, when comparing the result between SV and anti-fatigue™ lenses, the latter did demonstrate a slight lowering of the symptoms' score, there were no statistically significant differences between them (Lee, 2011). For Zeiss Digital lenses, a study conducted on 49 participants by the scientists at Carl Zeiss Vision shows that after two weeks of wearing the lenses, 46% of symptomatic participants no longer experienced asthenopic symptoms. The study also reported that accommodative facility was improved by nearly twice the amount when comparing to the participant's habitual corrections (Meister, 2016). Larrard et al. (2015) conducted a single blind survey study using the Essilor Eyezen™ lenses on three different age groups, and reported that regardless of the near additional power in the lens, 91% of the wearers preferred wearing the ESVLs and their asthenopic symptoms were reduced comparing to wearing their habitual spectacles. However, a certain level of bias may be present in this study, because participants knew that they were given a new pair of spectacles and there was no placebo or control group to compare the result to. Therefore, care must be taken when analysing the effect of such lenses on asthenopic patients.

Based on the concepts used for the development of ESVLs, the incorporation of a small amount of addition power may be beneficial in reducing the load on the ocular accommodation and improves the presence of lag of accommodation at near (Bao et al., 2013; Gwiazda et al., 2004; Koomson et al., 2015; Koomson et al., 2016; Rosenfield and Carrel, 2001). Near addition power also reduced the convergence of the eyes by inducing a heterophoric shift in the exophoric direction, which was shown in a study (Choy et al., 2000) to improve the asthenopic symptoms related to extraocular muscle stress. Because there was no other study conducted to determine the effectiveness of ESVLs in reducing asthenopic symptoms, the efficacy of ESVLs was non conclusive.

In this study, ESVLs were reported 37 times among the 62 (83%) respondents who prescribed treatment for asthenopic patients. The response was relatively high because it represents more than half of the respondents in this group, showing that ESVLs were a popular treatment prescribed by Singapore optometrists. The second most commonly reported treatment option was PALs (f=26). The concept of PALs treatment is very similar to ESVLs, whereby the accommodation effort and extraocular muscle misalignment at near is reduced. Even with a similar concept, ESVLs had a significantly higher response rate than PALs, which might be due to the psychological impression that PALs are mainly for presbyopes, therefore becoming unacceptable by pre-presbyopes, because it seems to represent a form of correction for age-related vision conditions (Meister, 2016). ESVLs, on the other hand, are marketed under branding such as anti-fatigue™, Digital lenses or Eyezen™, creating a different impression to the pre-presbyopes, thereby being more psychologically acceptable to them.

Also, most PALs near addition power may only start with 0.75 D onwards. Therefore, some practitioners may consider the addition power to be higher than ESVLs, which may skew the practitioner's preference towards a lens design that provides just enough addition power to relieve the accommodation (Meister, 2016). Peripheral distortion in ESVLs was also claimed to be lesser than PALs, thereby, requiring minimum adaption to the presence of distortion, making it a better choice for pre-presbyopics (Meister, 2016).

SVN lens was the third most commonly reported treatment option (f=24). Although using the same concept as the near addition power, some practitioners may still prefer SVN lenses to ESVLs and PALs, the reason being that during long hours of desk-top computer usage, lenses with near additional power may not be able to alleviate the symptoms of asthenopia; this is because the wearer may not be viewing through the near addition located at the lower part of the lenses because the computer screen is at eye level, and is therefore unable to reach the optimum effect of reducing the accommodation or extraocular muscle effort. Due to ergonomic conditions, the SVN lens remains a common option for some of the optometrists in this study but they are not as popular as ESVLs and PALs, possibly due to the inconvenience of bringing two pairs of spectacles daily.

VT has been shown to be effective in providing long-standing relief to asthenopic conditions related to convergence insufficiency (Brinbaum et al., 1999; Westman and Liinamaa, 2012), near-work induced transient myopia (NITM) (Ciuffreda and Ordonez, 1998) and accommodation (Cooper et al., 1987). However, in this study, VT was not the most commonly prescribed choice of treatment (f=12). VB is another common treatment that should be proposed to individuals involved with long hours of near work because fixation on near objects for a substantial period may result in asthenopia (Grisham et al., 1993; Iribarren et al., 2001; Owens and Wolf-Kelly, 1987). Henning et al. (1997) compared between computer worker typing performance at baseline and when they were allowed a 30 second to 3 minute short break, it was found that regular short breaks improved productivity. By taking short VB, it can also reduce the accommodation and vergence responses (Rosenfield, 2011). Similar to VT, VB was also not a common treatment option given to patients with asthenopia by Singapore optometrists (f=10) in this study. The reasons for VT and VB not being commonly prescribed as compared to ophthalmic lenses was unknown because respondents were not required to provide any details for their responses.

In recent years, there has been the suggestion that the blue light emitted from digital devices may result in a form of eyestrain known as digital eyestrain (DES). Blue light refers to the wavelength, within the visible spectrum, between 380 to 500 nanometer (nm) (Rosenfield, 2016). Exposure to blue light from digital devices has been reported to cause sleep deprivation because blue light has been shown to affect the sleep cycle due to suppression of melatonin production (LeGates et al., 2014; Tosini et al., 2016). It was also shown to possibly affect the mood and task performance of an individual (Legates et al., 2014). Another study performed on young adults have also showed that exposure to blue light from electronic devices, especially at night, could increase the risk of shorter sleep duration, longer sleep-onset latency and increased sleep deficiency (Hysing et al., 2015; Rosenfield, 2016). Although no scientific study has related blue light to eyestrain, it has been suggested that wearing ophthalmic lenses that contain a blue light filter (BLF) could reduce DES.

Cheng et al. (2014) reported an improvement in DES symptoms in a dry-eye group with low, medium and high-density BLF wraparound goggles worn during computer work, thereby showing that BLF was indeed able to reduce DES. However, Rosenfield et al. (2016) commented that the study did not provide any control condition; because participants were aware of the treatment given, it may therefore have created a biased result. Also, the wrap around goggles might have reduced tear evaporation, indirectly leading to improvement of symptoms in the dry-eye group. Therefore, the use of BLF in alleviating asthenopia remains inconclusive. In this study, prescribing of BLF lenses was only responded six times, showing that it was not a common solution for eyestrain symptom treatment among Singapore optometrists.

Another treatment option that was responded by the study participants was reducing the myopic prescription of their asthenopic patients (f=6). Lowering of myopic prescription might be based on the knowledge that myopic individuals tend to have a higher amount of lag of accommodation when being fully corrected (Gwiazda et al., 1993; Gwiazda et al., 2004; Gwiazda et al., 2005; Koomson et al., 2015; Koomson et al., 2016; McBrien and Millodot, 1986; Nakatsuka et al., 2005). With the understanding that asthenopia can be caused by accommodative lag during near work (Chase et al., 2009; Tosha et al., 2009) and by under-correcting the myopic correction, the amount of accommodative lag could be reduced (Koomson et al., 2015), thereby relieving the individual from the near vision ‘stress’ resulting from the defocus. Besides that, myopes are less sensitive to blur (Rosenfield and Abraham-Cohen, 1999) and by lowering the prescription slightly for each eye, minimum blur vision may be noticed as the summation effect of both eyes’ vision will still provide ‘clear’ vision without interrupting their lifestyle. However, lowering of myopic prescription may be contradictive, because studies have shown that wearing undercorrected prescriptions may result in a higher risk of myopia progression (Adler and Millodot, 2006; Chung et al., 2002). Knowing this consequence might have resulted in the low response rate for this treatment option.

In this study, eye drops were the least commonly prescribed treatment (t=3) to alleviate asthenopic symptoms among the 62 surveyed optometrists. As mentioned previously, asthenopia was classified as either internal or external symptoms (Sheedy and Shaw-McMinn, 2003; Sheedy, 2007). Dry eyes have been identified as the external symptoms for asthenopia based on its sensations, location and causes, which were almost related to irritation of the corneal surface due to dry eyes (Sheedy, 2007). It was reported by Tan et al. (2014) that the dry eyes disease in Singapore had a prevalence rate of 12.3%. Also, the prevalence of CL wearers in Singapore, based on a reported in the year 2000, was about 9% (Teo et al., 2011) and this number would have increased over the years. Even though with the substantial numbers of dry eye condition and CL wearers, it was surprising that eye drop treatments for dry eyes related to asthenopic symptoms was relatively uncommon.

Regardless of treatment options, among the 62 respondents who prescribed treatment to ocular fatigue patients, 72% of the respondents responded that the treatment options they prescribed were successful in reducing the asthenopic symptoms, even when the majority of study respondents did not use any type of optometric symptom survey form to grade the symptom score before and after intervention was administered. The study finding shows that Singapore optometrists were confident that the treatment methods prescribed were effective.

5.5.3 MFSCLs as a Treatment Option for Asthenopic Conditions

The following section describes the themes identified from the responses where participants stated that they have not considered the use of MFSCLs as a treatment option.

I. Lack of Scientific Evidence

One of the main reasons for not considering the use of MFSCLs as a treatment option for asthenopic condition was found to be the lack of scientific evidence to show the effectiveness of using such lens design in relieving ocular asthenopic symptoms. Many respondents either felt that there are no studies reported to show that MFSCLs can be used as a treatment option for ocular fatigue, or that they were not confident that this treatment option would help to alleviate asthenopic symptoms. For instance, one of the female respondents (institution worker, age 32) commented that she *'has not seen many studies recommending MF lenses as a proven method of treatment for ocular fatigue'*. Another respondent (private practice worker, age 50) stated that she was '*not very sure about the lens being helpful with visual fatigue as company did not label it for such use'*. One of the hospital worker respondents (age 24) further commented that she was also *'not sure if the lens works and was not being told they can be use to treat patients with visual problems'.*

In fact, to date, only two studies by González-Meijome (2011) and Hua et al. (2012) have shown that MFSCLs were able to reduce the symptoms of visual discomfort (see Section 2.6.4).

Besides these two studies, there were no other studies conducted to demonstrate the ability of MFSCLs in relieving asthenopic symptoms. Even though no strong scientific evidence was available, it had been suggested that MFSCLs could be used as a treatment option for accommodative dysfunction (Chu and Huang, 2010). Also, Edmondson et al. (1985) reported that MFSCLs could be used to manage near point problems caused by either accommodation or binocular vision issues in non-presbyopic patients. However, his symposium was based mainly on cases that MFSCLs were successful in alleviating the ocular issues of his patients and was not based on any scientific research.

Thus, the scarcity of research providing substantial evidence showing that MFSCLs can be used to reduce asthenopic symptoms in pre-presbyopic individuals may be the main reason why the study participants would not consider using MFSCLs as a treatment option for asthenopia.

II. Lack of Awareness and Experience

Lack of awareness and experience with fitting MFSCLs was the second most reported reason for not considering the use of MFSCLs for asthenopic treatment. Study results revealed that many respondents did not consider using MFSCLs as a treatment option either because (a) the use of such lenses did not occur to them or (b) that they did not know that such an option could be a potential treatment for ocular asthenopia. One of the institution worker respondents (age 34) commented that he *'never thought that this treatment would be effective'*. A manufacturing sector respondent (age 28) also stated that she *'has not thought about it as an option'*. A private practice worker respondent (age 45) stated that he *'was not told that it can be done'.*

In addition, a number of respondents stated that they do not have sufficient knowledge or experience with MFSCL fitting, in particular optometrists who work in hospitals or ophthalmologist clinics, thereby they do not consider using this method as a treatment option for asthenopia. As ophthalmologist clinic respondent (female, age 23) stated: *'I do not have much knowledge of the lenses because in clinic we don't fit contact lenses…'*. A hospital worker (male, age 34) also commented that optometrists *'don't fit contact lenses in hospital and don't have much knowledge on it'*.

As previously mentioned, to date there are a lack of studies showing that MFSCLs are an effective treatment for asthenopic symptoms. In addition, commercially available MFSCLs products are not labelled for such used. As stated by study respondents, the lack of information on MFSCLs contributes to their unawareness of such a treatment option. In comparison to monovision fitting, MFSCLs fit does requires a certain level of lens fitting knowledge and experience (Benjamin and Borish, 1994; Kollbaum and Bradley, 2014; Pérez-Prados et al., 2017). Lacking such knowledge might result in MFSCLs not being optimally fitted (Benjamin and Borish, 1994; Fedtke et al., 2016a; Pérez-Prados et al., 2017). According to an international survey for prescribing CL for presbyopes (Morgan et al., 2011), it was indicated that Singapore has zero case of MFSCL use for presbyopes. Although over the years, the number of MFSCLs being prescribed might have increased, the lack of experience of MFSCLs fitting might still be common among many Singapore optometrists.

III. Side Effects

In this survey study, the theme side effects from the use of MFSCLs was the third most reported reason for not considering it as a treatment option. Some of the participants showed concerns that the use of CL can induce dry eyes or even worsen the fatigue condition of patients. One of the private practice respondents (female, age 31) commented that *'fatigue complains usually comes together with dryness. Contact lenses may worsen dryness issue'*. A hospital worker respondent (female, age 27) stated that *'the contact lenses may exacerbate the symptoms of ocular fatigue'*.

It was previously reported that the prevalence of CL wear in Singapore, in the year 2000, was 9.0% (Teo et al., 2011). However, over the years, this number would have increased as the population in Singapore has grown. Teo et al. survey (2011) regarding CL complications in Singapore showed that 8.1% of their 721 participants reported dry eyes. By applying this prevalence rate onto the total number of CL wearers in Singapore, it would demonstrate that dry eyes could be relatively high among CL wearers in Singapore. As asthenopia can be caused by external symptoms either primary or secondary to dry eyes (Sheedy et al., 2003; Sheedy, 2007), the concerns by the survey respondents were reasonable that CL might cause some other side effects in addition to the existing asthenopia.

IV. CL Wearers and Alternative Method

Study results revealed that a number of respondents would only consider MFSCLs as a treatment option for patients who are already CL wearers. Study participants argued that CLs might cause discomfort to the patients who are not accustomed to CLs. A hospital worker (age 38) stated that *'If patient has never wore contact lenses before, then they might have problems adapting to contact lenses'*.

The Tear Film and Ocular Surface society (TFOS) (Dumbleton et al., 2013) reported that discomfort with CLs can be caused by either non-modifiable factors (i.e., gender, age, ethnicity, blink rate), or modifiable factors (i.e., medication diet, hydration, smoking, cosmetics, etc.). These factors are quite diverse and were similar to the factors that could result in dry eyes. Therefore, the study respondents have valid concerns over causing additional discomfort such as dry eye condition and are only considering MFSCLs for existing CL wearers.

Several respondents stated that they would rather prescribe other methods to alleviate the symptoms of asthenopia because they feel that spectacles and VTs might be more successful compared to MFSCLs. For instance, a private practice respondent (male, age 38) felt that *'additional work is needed to fit CL'*, therefore, preferred options will be to use spectacle lenses to treat the condition, which can be simpler and direct. Besides that, the performance of MFSCLs may vary among individuals due to factors such as pupil size, lens design, power profile of the lens, lens centration and the amount of addition used (Fedtke et al., 2016b), which requires a certain level of MFSCL fitting experience. A private practice respondent (male, age 54) commented that *'where possible if spectacles and free space techniques can do a better job, they will be first choice'*.

V. Poor Visual Quality

Poor visual quality with MFSCLs was another concern by some of the study respondents since most of the commercially available MFSCLs design used simultaneous imaging to provide distant and near visual correction for presbyopia. As discussed in Section 2.6.1, regardless of whether centre–distant or centre–near design, these lenses create superimposed distant and near images within the visual system and require the wearer to suppress the blurred image and choose the clearest for the visual task (Pérez-Prados et al., 2017). Due to the superimposed imaging system of the lens, a certain amount of degradation to the visual performance will occur when comparing to SVCLs (Fernandes et al., 2013; Gupta et al., 2009; Llorente-Guillemot et al., 2012; Madrid-Costa et al., 2013; Rajagopalan et al., 2006). The knowledge of possible visual quality degradation may indeed discourage optometrists to consider using MFSCLs as a treatment option for ocular asthenopic patients in a fear of increasing asthenopia due to the degraded vision. As institution worker respondent (female, age 42) stated: *'some patients didn't get satisfactory vision from multifocal contact lenses, especially with Mid to High ADD cases'.* An ophthalmologist clinic respondent (age 32) commented that she *'don't think it will work as MFSCLs may induce more blur vision due to the multiple power in the lenses compare to ophthalmic lenses. It might cause more problems to the current visual fatigue'*.

Nonetheless, multiple studies (Gupta et al., 2009; Llorente-Guillemot et al., 2012; Madrid-Costa et al., 2013; Rajagopalan et al., 2006) conducted on presbyopic subjects have shown that simultaneous MFSCLs were able to provide good binocular visual acuity in photopic condition, with some showing decreased contrast sensitivity function in the mesopic condition. Recently, Fedtke et al. (2016b) conducted a study to determine visual performance between SVCLs and all commercially available MFSCLs on pre-presbyopes (Section 2.6.3). The study showed a decrease in the HCVA while wearing simultaneous imaging design lens as compared to SV control lenses. For some lenses (i.e., Air Optix multifocal low add, Proclear multifocal centre-distance high and low add and PureVision multifocal low add), the differences in the HCVA between them and the SVCL was clinically small. Also, in the study, with SVCLs, participants could reach HCVA of -0.10 logMAR, while Air Optix LAMFCLs and HAMFCLs were able to achieve a HCVA of -0.05 logMAR and 0.03 logMAR, respectively; this shows that visual acuity was only marginally affected by the MFSCLs, and that a HCVA close to or better than 0.00 logMAR can still be achieved. Although reasonably good visual acuity can be provided by MFSCLs, the visual performance may vary with lens design; with the majority of the low addition lenses achieving better vision ratings than high addition ones.

Fedtke et al. (2016b) also highlighted that insufficient adaptation period for wearing the MFSCLs were given to their participants, and that studies (Fernandes et al., 2013; Montés-Mićo and Alió, 2003) have shown that after a period of adaptation to simultaneous imaging lenses, contrast sensitivity and visual performance improved. Based on these results, the author suggested that future work is essential to assess the subjective visual performance with MFSCLs after a longer period of adaptation.

Another study by González-Meijome et al. (2011) using MFSCLs with young adults had shown that visual acuity was comparable to SV lenses under high and low-contrast conditions. Jong et al. (2011) investigated the visual performance and subjective satisfaction with MFSCLs at near work, and showed that a VA of 6/6 can still be maintained binocularly with multifocal low add centre-near lenses for all viewing distance after two weeks of lens wear. When comparing VA of MFSCLs to SVCLs, there was no significant difference found for distance (p=0.72) and near (p=0.65). Participants' satisfaction survey also indicated that the majority of university students preferred MFSCLs to SV lenses because they provide better visual performance at near work. Due to these results, the author (Jong et al., 2011) suggested that MFSCLs are helpful for young adults involved in prolonged near work.

Even with studies (Fedtke et al., 2016b; González-Meijome et al., 2011; Jong et al., 2011) demonstrating that reasonably good visual performance can be achieved in pre-presbyopes while wearing MFSCLs, the concern of poor VA still discourages Singapore optometrists to consider MFSCLs as a treatment option for asthenopic patients.

VI. Costing and Limitation

Only two study respondents indicated their concern over the cost of using MFSCLs for asthenopic patients. A private practice respondent (age 54) stated that many of his patients were children, and parents might not be able to afford expensive CLs. He commented: *'cost also a factor. Many patients are children whose parents may not be keen to have them put on contact'*.

Another concern of two other study participants was the limitation of the contact lens parameters. An institution worker respondent (female, age 41) commented that *'current multifocal contact lenses have limited parameters. For example, Toric not available'*. Currently in Singapore, commercially available MFSCLs only come in spherical powers with no astigmatism correction. Masking of astigmatism can result in blurring of the visual quality and may worsen the asthenopic condition (Wajuihian, 2015). It is indeed a factor that requires consideration since it may worsen already existing asthenopic symptoms.

Reasons for Considering MFSCLs

The following section describes the themes identified from responses where participants stated that they have considered the use of MFSCLs as a treatment option.

I. Effectiveness of Lenses

A number of study respondents felt that MFSCLs could be beneficial to asthenopic symptomatic patients because they believe that MFSCLs are able to either reduce eyestrain at near, relax the eyes or even reduce the accommodation effort at near. A private practice respondent (male, age 30) stated that MFSCLs *'helps reduce strain for near work'.* Another private practice worker (male, age 53) commented that *'it can relax the eye'*. A supply chain respondent (male, age 31) elaborated: *'A low add Multifocal (especially) if Centre Distance design or purely LOW ADD (Centre near aspheric Max +1.00) helps patient to reduce amount of accommodation during their day to day intensive near work'*.

These responses indicated that some optometrists believe that the presence of the addition in MFSCLs is similar to PALs or ESVLs, which can relax the accommodation at near, thereby reducing the amount of accommodation required. A private practice worker respondent (male, age 24) stated that *'spectacle lens like Zeiss digital and Essilor eyezen helps to alleviate eye fatigue issues as well'.*

As reviewed in Section 2.6.5, Tarrant et al. (2008) showed that simultaneous imaged design lenses caused changes to the lag of accommodation in their young adult participants, with a near addition of +1.50 D resulting in the initial lag of accommodation to become a lead of accommodation; this result indicated that young pre-presbyopic accommodation was affected by the near addition of simultaneous imaged CLs.

Gong et al. (2017) reported that the accommodative lag of children in their study was slightly higher with MFSCL than SVCL wear. The author explained that the reduction of accommodation response might be due to the utilisation of the positive addition of the MFSCLs, which relaxes the accommodation and/or the positive SA induced by the MFSCLs, which together with the ocular SA created a larger depth-of-focus within the visual system, thereby providing a larger range of clear vision, which indirectly reduced the need for the children to accommodate. The children in the study also exhibited an increase in near exophoria: this finding agrees with the conclusion that accommodation was indeed relaxed by the MFSCLs. Similarly, in Kang and co-workers' study (2016), exophoric changes were observed without any changes to the lag of accommodation; this leads to the author suggesting that the exophoric shift could be due to a change in the accommodation induced by the MFSCLs.

In contrast, Pettersson et al. (2011) reported that young pre-presbyopic individuals when fitted with an addition of +1.00 D centre-distance design

MFSCLs did not show any signs of relaxation to their accommodation. Madrid-Costa et al. (2011) also indicated in their report that MFSCLs did not cause any accommodative and pupil response changes in their pre-presbyopic participants, when fitted with centre-near MFSCLs as compared to SVCLs, for two different accommodative stimuli. Therefore, both studies suggested that MFSCLs were not effective in affecting the accommodation response.

Barodawala and Dave's (2014) study on accommodative lag in young myopic adults using centre-near LAMFCLs reported increased lag of accommodation after wearing MFSCLs and suggested that the near addition of MFSCLs was not effective in improving the near focusing. Lee et al. (2015) compared the accommodative function of young adults wearing three different types of lens conditions: monovision, modified monovision and aspheric multifocal low addition with a centre-near design, and showed that the accommodative responses of the MFSCLs to the SVCLs during the 2.50 D stimulus was very similar. Even though MFSCLs accommodative response appears to be slightly better when comparing to the SVCLs, the result was statistically insignificant, leading to the conclusion that the MFSCLs in the study did not relax the accommodation.

Even though when the conclusion on the effectiveness of MFSCLs affecting the accommodative response in young adults is still currently non conclusive, many optometrists in this study felt that MFSCLs can relax the accommodation while conducting near work; therefore, this becomes the strongest reason why they would consider fitting MFSCLs on asthenopic symptomatic patients.

II. CL Wearer

The second-most-reported reason for considering fitting MFSCLs for asthenopic conditions was suitability for existing CL wearers (similar reason for not considering MFSCLs for patients who are not CL wearers in the first place). The study participants agreed that they would only consider this option if the asthenopic symptomatic patient was a current CL wearer, if not, they would rather consider the use of spectacles as a treatment. A private practice worker respondent (female, age 26) commented that '*MFSCLs would be more suitable for patients who are more inclined to wear contact lenses only'.* Another private practice respondent (age 36) stated that he would consider MFSCLs *'only when the patient prefers to wear contact lenses during work'.*

The reasons for only considering MFSCLs for the existing CL wearers could be similar to the reasons stated previously, such as adaptation and inducing of discomfort and dryness to the eyes; this indicates that Singapore optometrists are likely to be exploring this treatment option only for existing CL wearers, which is a logical decision since some patients, who could already be wearing spectacles, might not be comfortable with wearing CLs.

III. Cosmetic Reason

Another theme discovered among the respondents who have considered MFSCLs was cosmetic reasons. Some of the study participants felt that they would consider MFSCLS as an option due to convenience and for patients who dislike wearing of spectacles. As private practice respondent (male, age 36) commented '*if customers do not like wearing glasses, this is an alternative for eye fatigue'*. Another private practice respondent (female, age 22) further argued that '*for those patients that don't like to be seen wearing spectacles, they are good candidates for contact lenses'.*

The cosmetic reasons for using MFSCLs are very subjective and should be considered with caution.

IV. MFSCLs for Younger Patients

In this study, a retail sector respondent (age 23) felt that he would only recommend the use of MFSCLs as a treatment for asthenopic condition if the patient is approaching 40 years of age and may have mild symptoms of early presbyope. He commented: *'It would depends on the age of the patient. If the patient is nearing 40 and becoming mildly presbyopic. I would consider MFSCLs as an option'*.

In contrast, two respondents felt that they would consider prescribing MFSCLs to younger patients. The reason was that PALs were prescribed to children as young as 13 years. Therefore, a private sector respondent (age 22) believed that MFSCLs could be one of the considerations should there be a need. He commented: *'I've prescribed PAL as a treatment option for a 13 year old before. Hence, multifocal contact lenses were considered'.* There is currently no regulation in Singapore regarding a patient's age when fitting CLs, and there is also no report to show the youngest age group of CLs wearers. Only two respondents felt that they would consider this option for younger patients and more research is required to confirm whether MFSCL treatment is suitable for younger patients.

V. Personal Experience

Another reason for considering MFSCLs as a treatment option was based on personal experience with the MFSCLs. A private practice respondent (female, age 22) explained: *'I have wore MF soft lenses (Airoptix) in school for learning purposes, and yet I don't find any difficulty in far and near vision'.*

As discussed in Section 2.6.3, vision may not be drastically affected by MFSCLs and depending on the near addition and lens fit, some MFSCLs could provide up to 0.00 logMAR distant vision (Fedtke et al., 2016b). Therefore, based on personal experience with wearing MFSCLs, it might boost the confidence of the practitioners in understanding the type of vision that a patient might have, and it may increase the possibility for practitioners to consider using MFSCLs as a treatment option.

5.6 Conclusion

The findings from the present study show that about three quarters of those surveyed do see ocular fatigue patients, with an average close to nine (8.97, SD 9.80) ocular fatigue patients diagnosed in each month, which may indicate that ocular fatigue can be relatively common in Singapore. According to the study participants, tired eyes, blurred vision at near and headaches or migraines were the most commonly reported fatigue symptoms. The study finding also indicated that the majority of optometrists do provide treatment to ocular fatigue patients but only a relatively small proportion (9%) of participants, among those who encounter ocular fatigue patients, utilised optometric symptom survey forms to determine the presence and severity of ocular fatigue during eye examination.

The present study also shows that ophthalmic lenses with near addition power were the most commonly prescribed treatment to alleviate symptoms of asthenopia. The finding was quite interesting because it was known that asthenopia might be due to internal issues (Sheedy et al., 2003; Sheedy, 2007) arising from either the visual function of accommodation or when ocular convergence was being stressed. However, even if the asthenopic condition is related to internal issues, there will be conditions: (i.e. convergence insufficiency) which should not have responded to the use of near additional power in the ophthalmic lens. Nonetheless, 72% of participants who prescribe a treatment to their patient with asthenopic conditions, reported that treatment was successful in alleviating or reducing the symptoms of their patients.

It was also found that the majority of Singapore optometrists have not considered MFSCLs as a treatment option for ocular fatigue patients. The most common reason for this discrepancy provided by respondents was the lack of scientific evidence to show that MFSCLs are able to relieve fatigue symptoms. Besides that, some Singapore optometrists responded that they were either unaware that MFSCLs could be a treatment option or that they were not familiar with fitting MFSCLs. A minority of the respondents indicated that MFSCLs could be an effective solution for ocular fatigue patients because of the near addition power in the lens.

The limitation of this study was that the survey research was conducted with minimal communication with the participants. As the popularity of Internet usage increase, conducting survey research online improved the ability to reach and invite certain groups and individual to participate. Also, it allows participants to reply during their free time, which can increase the response rate (Wright, 2005). However, the disadvantage is that the respondent might not interpret the question correctly and there is no way to explain it to them adequately (Milne, 1999). Therefore, certain information required to better understand the reason(s) for their response was not possible; in other words, to determine in detail how Singapore optometrists diagnosed ocular asthenopia in their patients and the definition they used to classify ocular asthenopia.

In this study, the questionnaire did not indicate the definition of ocular fatigue clearly to the participants. Because of the lack of precise definition, it depends mainly of participants' perception on what ocular fatigue is. This assumption may cause a huge variation in the response for questions such as 'during the course of your practice, do you see patients with ocular fatigue symptoms' and 'on average, how many ocular fatigue patients do you encounter in a month'. Indeed, in this study, the range of ocular fatigue cases encounter within a month had a range of 49, which was relatively huge. This variation might be due to unclear explanation to the definition of ocular fatigue (Hashemi et al., 2017; Ostrovsky et al., 2012; Vilela et al, 2015). Therefore, future study should include a precise definition of ocular fatigue to minimise the variation in responses.

It would be beneficial in future work to conduct another optometric survey with the Singapore optometrists to determine: (1) how asthenopia is being diagnosed, (2) why ophthalmic lenses with near addition power were so commonly used, (3) how they determined when to prescribe such lenses and (4) why VT and eye drops were not commonly used. These proposed questions would provide in-depth information regarding the diagnostic method(s) for asthenopia and the reason why ophthalmic lenses were more preferred than VT and eye drops for treating asthenopic conditions in Singapore.

6.0 General Conclusion

Investigations on simultaneous image MFSCLs have been conducted for many years (Gupta et al., 2009; Llorente-Guillemot et al., 2012; Madrid-Costa et al., 2013; Rajagopalan et al., 2006), and even though our understanding regarding their optics and visual performance on both pre-presbyopes and presbyopes have improved over time (Fedtke et al., 2016b; Gupta et al., 2009; Llorente-Guillemot et al., 2012; Madrid-Costa et al., 2013; Rajagopalan et al., 2006), the effectiveness of MFSCLs in relieving asthenopic symptoms in pre-presbyopes is still uncertain. There is very little literature relating to either the use of MFSCLs on visual symptoms (González-Méijome et al., 2011; Hua et al., 2012) or the effect on the pre-presbyopes accommodative responses (Barodawala and Dave, 2014; Gong et al., 2017; Kang and Wildsoet, 2016; Lee et al., 2015; Madrid-Costa et al., 2011; Pettersson et al., 2011). Due to the fact that there is a high prevalence of CL wearers in Singapore (Teo et al., 2011) and with the increasing duration (Digitalinfluencelabcom, 2015; Lin and Toh, 2017; Tnsglobalcom, 2015; EY, n.d) and decreasing viewing distance (Bababekova et al., 2011; Long et al., 2017) of near work, symptoms associated with ocular asthenopia may also escalate (Grisham et al., 1993; Murata et al., 1996; Owens and Wolf-Kelly, 1987). Therefore, the primary aim of this thesis was to investigate the possibility of MFSCLs in relieving asthenopic symptoms in orthophoric and esophoric pre-presbyopic myopes with lag of accommodation.

The present thesis has shown an association between asthenopic symptoms and MFSCLs, where the asthenopic symptoms scores were ameliorated with the use of MFSCLs. In Chapter 3, CISS scores of asthenopic participants wearing either SPECT or SVCLs were significantly improved using LAMFCLs or HAMFCLs. The effect of MFSCLs near addition on accommodative lag was also investigated to determine whether improvement to focusing could be achieved. The findings revealed that no significant difference in the accommodative lag was observed after wearing MFSCLs, showing that pre-presbyopes were not reacting to the near addition in the MFSCLs; this finding is similar to some of the studies (Kang and Wildsoet, 2016; Madrid-Costa et al., 2011; Pettersson et al., 2011) previously conducted. Furthermore, assessment of distance and near heterophoria was also conducted for SPECT and all the CLs used in this study. The finding demonstrated that distance heterophoria shows an esophoric shift for all CL wearers when comparing to SPECT. Near esophoric shift was also observed when switching from SPECT to SVCLs. These findings are similar to those of Jiménez et al. (2011), where increased esophoria was observed when changing from SPECT to CLs. Interestingly, both LAMFCLs and HAMFCLs led to a lesser esophoric shift at both distance and near when compared to SVCLs, with the near heterophoria showing a larger shift in the exophoric direction; this finding is consistent with studies (Gong et al., 2017; Kang and Wildsoet, 2016) reporting exophoric shift without any accommodative response changes observed with MFSCLs in pre-presbyopes.

There was no strong evidence showing that both orthophoric or esophoric pre-presbyopic myopes in this study were using the near additions power of the MFSCLs and that the near esophoric status was not significantly changed. There might be the possibility that the negative SA from the centre-near

MFSCLs increases the depth-of-focus (Bakaraju et al., 2010a; Fedtke et al., 2017), which raises the tolerance to the minor degradation of image quality (Applegat et al, 2003; Chen et al., 2005; Cheng et al., 2004; Tarrant, 2010), thereby reducing the asthenopic symptoms. Clearly, more work is required to understand and consider the use of MFSCLs in a wider asthenopic group. It would be prudent for future work to consider the inclusion of exophoric myopes, which can provide insight on the effectiveness of MFSCLs in alleviating asthenopic symptoms and providing information on the accommodative and heterophoria status in this group to compare with the current study findings.

The accommodative response of the pre-presbyopic participants wearing MFSCLs immediately, and after one month of wear, was also investigated using clinical methods described in Chapter 4. The results highlighted that there was improvement to the AoA and NPC while wearing either LAMFCLs or HAMFCLs as compared to SPECT and SVCLs, suggesting that pre-presbyopes were using the near addition power of MFSCLs, therefore improving the accommodative and convergence ability. However, these improvements might have resulted from the extreme pupil miosis that can occur because of the closeness of the target during the push-up test. Changes to the relative accommodation were also observed, with a significant increase in PRA and decreased in NRA value for HAMFCLs at a 40 cm test distance, which was identical to results of Lee et al. (2015), suggesting that the MFSCLs' near addition might have affected the accommodative response. However, accommodative response affected by the MFSCLs near addition was not supported by the accommodative lag finding in Chapter 3. Therefore, the relative accommodation changes might be due to the exophoric shift result being secondary to the increase in negative SA created by the ocular and lens combination (Bakaraju et al., 2010a; Fedtke et al., 2017), creating a larger depth-of-focus and thereby lessening the accommodation required (Gong et al., 2017).

As a result of the study placing a limitation on the pupil size measurement at the end point of AoA measurement, future work should consider using digital photography for the measurement of pupil size, which is similar to the method of Cardona and Lópex (2016). As most clinical practices may not have equipment such as an open-field autorefractor to objectively measure the pupil size, therefore, even though this may not be the best way of measuring the size of the pupil, it will provide a basic pupil size measurement during the push-up test. In both Chapters 3 and 4, the main objective was to use clinical methods to assess the effectiveness of MFSCLs in a real-life clinical testing setting, and therefore SA could not be evaluated. Future studies could consider the use of an aberrometer to determine whether the level of SA was indeed significantly increased by the ocular and lens combination in pre-presbyopes during near tasks; this would provide a better understanding of the possibility of negative SA resulting in reducing the blurred vision, thereby improving the symptoms' score and causing the exophoric shift observed in both chapters.

Although a previous study (Madrid-Costa et al., 2011) had suggested that longer adaptation period with MFSCLs might result in improvement in accommodative response, this study reported in Chapter 4 no improvement in accommodative response after one month of wear. Future work might consider a longer adaptation period of 3−6 months with MFSCLs to investigate whether there will be any improvement to the accommodation and binocular vision condition (Madrid-Costa et al., 2011; Montés-Mićo and Alió, 2003).

Because there was no information regarding how optometrists in Singapore detect and manage asthenopic conditions. Chapter 5 of the present thesis surveyed 100 optometrists to better understand the situation. The survey also examined whether MFSCLs had been considered as a treatment option for asthenopic patients and the reasons for their response. The finding shows that three-quarters of the surveyed optometrists reported seeing asthenopic patients, with an average of 8.97 (SD 9.80) asthenopic cases in a month, indicating that asthenopic conditions can be quite commonly seen in Singapore. It was also responded that tired eyes, blurred vision at near and headaches or migraine were the most commonly reported fatigue symptoms, which was similar to the symptoms reported in other studies (Alexander et al., 1985; McKay et al., 2002; Mvitu and Kaimbo, 2003; Neugebauer et al., 1992; Wajuihian, 2015; Westman and Liinamaa, 2012). For the majority of participants encountering with ocular fatigue cases, 83% of respondents do provide ocular fatigue treatment, but only 9% utilised symptom survey forms to determine the presence and severity of asthenopia. Among the type of treatments provided, ophthalmic lenses such as ESVLs, PALs and SVN lenses were the most commonly prescribed treatment options, and most respondents (72%) felt that the treatment options that they provided were successful in relieving asthenopic symptoms.

The survey finding also indicated that the majority (69%) of Singapore optometrists have not considered using MFSCLs for asthenopic symptom treatment. Lack of scientific evidence showing the effectiveness of MFSCLs in relieving asthenopia was the most common reason reported. A minority (31%) of respondents' felt that the near addition power in MFSCLs was able to relax accommodation and they had, therefore, considered the use of it. The limitation of this survey was that it was conducted through electronic survey forms and there was minimal communication with the participants. Therefore, certain vital information might not have been gathered. Future work should be carried out to further understand some of the responses from the respondents in details, such as the reason why ophthalmic lenses were commonly prescribed for ocular fatigue patients.

6.1 Concluding Statement

The results presented in this thesis offer novel information to the optometric community with the knowledge on the effectiveness of MFSCLs in relieving visual fatigue among pre-presbyopic myopes who were orthophoric or esophoric. This information will also allow a better understanding of 1) the effectiveness of MFSCLs for accommodative response on pre-presbyopes, 2) the possible changes to the binocular vision status that may result from

MFSCL wear, 3) the frequency of asthenopic cases seen in Singapore and the concern of Singapore optometrists regarding the use of MFSCLs as an asthenopic intervention.

The information in this thesis can be share with fellow optometrists either by publishing in journals or by presenting an abstract or poster in a conference (e.g. Singapore Optometric Association conference). With these information, optometrists will be equipped with more knowledge on the effect of centre-near MFSCLs with respect to the ocular accommodative and vergence systems of pre-presbyopes, and therefore, allowing better understanding on the usage of MFSCLs and providing improved optometric care to CL wearers with asthenopia that will be encountered during routine clinical practice.

As the current study only provides information on MFSCLs alleviating asthenopic symptoms in orthophoric and esophoric myopes. Future work should consider the inclusion of exophoric myopes, to determine whether the effectiveness of MFSCLs in relieving asthenopic symptoms will also apply to this group. The finding will provide vital information on the accommodative and heterophoria status and can be used to compare with the current study findings.

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Appendix 1: Ethics approval confirmation letter

Aston University Ethics Committee
Aston University
Aston Triangle
Birmingham
B4 7ET
Telephone +44 (0)121 204 3000
Fax +44 (0)121 204 3696

Chairperson: Ms Nichola Seare

Secretary: Mr John Walter

22nd January 2015

Dr Leon Davies

Life & Health Sciences

Dear Leon

Study Title: 'Efficacy of Multifocal Soft Contact Lens on Asthenopic Orthophoric and Esophoric Myopes with Lag of Accommodation'

REC Reference: PhD Student Ethics Application 719

Protocol Number:

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised.

The project is approved until the completion date specified provided it is commenced within two years of the date of this letter and you are required to notify the Committee when the project is completed.

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	EC Review Date
University Research Ethics Application Form	One	20/11/2014
Risk Elimination and Control Form	One	20/11/2014
Aston DOptom/DOphSc Project Proposal Form	One	20/11/2014
Research Study Participant Information Sheet	Version 1.0	20/11/2014
Volunteer Consent Form	Version 1.0	20/11/2014
Word Document showing response to Reviewers: University Ethics Committee Project 719	One	06/01/2015

Word document detailing amendments to the online application forms for PhD student ethics application 719	One	06/01/2015
Research Study Participant Information Sheet	Version 2 (24/12/2014)	06/01/2015
Volunteer Consent Form	Version 2 (24/12/2014)	06/01/2015
Email/ Facebook advert	Version 1 (16/01/2015)	16/01/2015
Email/ Facebook advert	Version 2 (22/01/2015)	22/01/2015

Statement of compliance

The Committee operates in accordance with the Aston University Ethics policy and procedures:

http://www1.aston.ac.uk/registry/for-staff/regsandpolicies/ethics-policy-and-procedures/

Reporting Requirements

The details of the investigation will be placed on file. You should notify the Secretary of the University Ethics Committee of any adverse events which occur in connection with this study and/or which may alter its ethical consideration, and/or any difficulties experienced by the volunteer subjects.

If you intend to make any future protocol amendments these must be approved by the Ethics Committee prior to implementation. You should also seek approval for any extension of the approved completion date.

Membership

The members of the University Ethics Committee present at the meeting are listed below:

- Ms Nichola Seare, AHRIC Director, Aston University
- Mr John Walter, Director of Governance, Aston University

REC reference: **PhD Student Ethics Application 719** **Please quote this number on all correspondence**

With the Committee's best wishes for the success of the project

Yours sincerely

[redacted]

Secretary of the Ethics Committee

Email [redacted]

Appendix 2: Ethics approval for amended request for research #719

Aston University
Aston Triangle
Birmingham
B4 7ET
0121 204 3000

Date: 21/06/2016

Dr Leon Davies
Life and Health Sciences

Study title:	**Efficacy of Multifocal Soft Contact Lens on Asthenopic Orthophoric and Esophoric Myopes with Lag of Accommodation**
REC REF:	Ethics application #719

Confirmation of Ethical Opinion

On behalf of the Committee, I am pleased to confirm a favourable opinion for the amendment to this research.

Documents approved

Document	*Version*	*Date*
#719 amendment request_survey form	1	20th June 2016

With the Committee's best wishes for the success of this project.
Yours sincerely

[redacted]

Dr Nichola Seare
Chair of the University Research Ethics Committee

Appendix 3: Participation information sheet

Research Study Participant Information Sheet

Please read this information sheet carefully before deciding to participate in this research study. You are free to ask any questions at any point before, during and after your participation in this research study.

Research workers, school and subject area responsible

Mr. Alex Ong Chee Horng, Optometry, Life & Health Sciences, Aston University
Dr. Leon Davies, Optometry, Life & Health Sciences, Aston University
Dr. Amy Sheppard, Optometry, Life & Health Sciences, Aston University

Project Title:

Efficacy of Multifocal Soft Contact Lens on Asthenopic Orthophoric and Esophoric Myopes with Lag of Accommodation.

Invitation to Participate:

You are invited to participate in this research study. Before you decide whether to participate, it is important for you to fully understand why the research is being conducted and what it will involve. Please take some time to read the following information regarding this research study carefully and ask any question relating to the research.

Purpose of the research study:

The purpose of this study is to investigate whether the use of multifocal soft contact lenses is effective in reducing the symptoms of eye strain in any person who has short-sightedness (myopic). There must also be presence of normal balance of the eye muscle (orthophoric) or slight inward misalignment of the eyes (esophoric) with a condition that causes inaccurate focusing on object at near (lag of accommodation).

We will also evaluate whether changing the amount of near prescription of the multifocal soft lenses modify the eye strain symptoms.

Data from this research study will provide more clinical information on the use of multifocal soft contact lens design in treating eye strain.

Where will the study take place?

[redacted]

What will happen to me if I participate?

By volunteering to participate in this research study, you will need to attend Ong's Optics on four occasions as detailed below.

In this study, an eye examination will be conduct on you to gather the following clinical data:

- Visual acuity/ vision
  - How well a person can see with/without spectacle correction.
- Contrast sensitivity
  - How well a person can distinguish between low-contrast targets (e.g. a grey letter on a white background)
- Pupil size
  - Measuring the size of the pupil.
- Binocular vision
  - Testing the ability of both eyes to work together to maintain focus on one point.
- Accommodation
  - Testing the ability of the eyes muscles to focus on a near object.
- Ocular surface health examination
  - Examine the health of the front part of the eyes which includes the eyelids, conjunctiva, iris, crystalline lens, sclera and cornea.

You will then wear three different types of commercially available soft contact lenses. Each lens will be worn for one month for at least five days a week and eight hours a day. The order that you wear these contact lenses will be chosen for you at random. Evaluation of your symptoms using the CISS form and the same eye examination will be conducted during each visit. The brand of the lenses you are trying will not be disclosed to you. However, you can ask the study investigator for more information regarding the lenses you are being asked to wear at the end of the study.

You are required to attend a maximum of four planned study visits over a period of up to 3 months.

<u>Visit 1- Eye examination and soft contact lens fit (approximately 45 minutes)</u>

Once you have given inform consent to participate in this study, an eye examination will be undertaken, which will include;

- Refraction
  - The refraction test is an eye exam that measures a person's prescription to determine whether there is myopia (shortsighted), hyperopia (longsighted) or astigmatism (oval shaped eye).
- Binocular vision test
- Accommodation test
- Contrast sensitivity test

- Pupil size measurement
- Ocular surface health examination

The study investigator will then fit you with a soft contact lens. Suitability of the contact lens will be assessed to ensure it is appropriate for you to wear. You will then be asked to wear the soft contact lenses for one month for at least five days a week and eight hours a day.

<u>Visit 2 - Follow up and soft contact lens fit (approximately 45 minutes)</u>

You will be asked to return, with the soft contact lens on your eyes, for a follow up visit on the 30^{th} day (+/- 2 days) of lens wear. An assessment of your symptoms (if any) will be made using the CISS form. Your eyes will also be examined as in visit 1.

The study investigator will then fit you with a second pair of soft contact lens. Suitability of the contact lenses will again be assessed. You will then be asked to wear the soft contact lenses for one month for a period of five days a week and eight hours a day.

<u>Visit 3 – Follow up and soft contact lens fit (approximately 45 minutes)</u>

You will be asked to return, with the second pair of soft contact lens that were prescribed to you, for a follow up visit on the 30^{th} day (+/- 2 days) of lens wear. An assessment of your symptoms will be made using the CISS form. You will also be given an eye examination similar to that in visit 2.

The study investigator will then fit you with a third pair of soft contact lenses. Suitability of the contact lens will again be assessed. You will then be asked to wear the soft contact lenses for one month with a period of five days a week and eight hours a day.

<u>Visit 4 - Follow up and study end (approximately 45 minutes)</u>

You will be asked to return, with the third pair of soft contact lenses that was prescribed to you, for a follow up visit on the 30^{th} day (+/- 2 days) of lens wear. An assessment of your symptoms will be made using the CISS form. You will also be given an eye examination similar to that in visit 3. Once you have completed the study, your eyes will be examined to ensure their health and all contact lenses will be removed by the investigator.

It is important that you follow the visit and wearing schedule as instructed by the investigator.

These study visits do not replace your regular periodic eye examinations, which you should attend.

Are there any possible risk or discomfort during the research study?

The risk involved with all the procedures and devices in this study is extremely low.

The soft contact lenses used in this study are commercially available and have been approved by the local authority for fitting and selling in Singapore. Therefore, the risk involved in wearing the soft contact lenses in this study are the same as those of wearing any other type of commercially-available soft contact lenses. You may initially experience slight blurring of vision; this is normal and can be resolved as you adapt to the soft contact lenses. If a complication should happen during the study (e.g. blurred vision), a longer consultation appointment may be necessary and you may be referred for medical treatment.

If you experience any eye discomfort, pain, redness of the eye, vision changes, or any other problems, you should cease using the study soft contact lenses and contact the investigator (Alex Ong Chee Horng, [redacted]

In an emergency, if you are unable to reach the investigator, please stop wearing the study soft contact lenses and go to your nearest Accident and Emergency (A&E) department immediately. Inform the attending staff of your participation in the study.

Do I have to participate?

No, participation in this research study is not compulsory if you do not wish to do so. Even if you are willing to participate now, at any point of time during the research study, you are free to withdraw. No penalty or legal action will be taken against any participants who do not wish to participate in or withdraw from the research study.

Any payment or expenses required?

There will not be any financial compensation for your participation in this research study.

Will my participation in this research study be kept confidential?

Yes, your identity in this study will be treated as private and confidential. All the data collected will be anonymised and will be kept confidential in accordance with The Data Protection Act 1998, UK. The only people that will have access to the data are the researchers noted on page 1. All the data recorded will not contain any information that can be used to identify you as a participant in the research study. Instead of using your name, a unique participant code will be assigned to the recording form. At the end of the research study, any personal information related to you will be destroy and only non-identifiable coded data will be retained. Should any data recorded from your participation required to leave the study site, it will not contain any information that can link to you.

What will happen to the results of the research study?

At the end of the study, the results, including all tests conducted or any other data will be analyzed. This research study will be used for the doctorate thesis that Mr. Alex Ong Chee Horng is currently undertaking. The results of the research study may be published in journals for learning or scientific purposes. In addition to the supply of any peer-reviewed publication, a lay summary of the research findings will be made available to all participants on request. Participants who are interested can e-mail us at: [redacted] and we can send a copy of the lay summarized published research to you.

Who is Organizing and Funding the research?

This research study is for a Professional Doctorate conducted by Aston University, United Kingdom. This research study is organized by Mr. Alex Ong Chee Horng, who is a qualified optometrist practicing in Singapore and a student of Aston University, and supervised by Dr. Leon Davies (Reader and Director of Research) and Dr. Amy Sheppard (Lecturer and Director of the Professional Doctorate programme) also from Aston University. This research study is not being funded by any organisation.

Who has reviewed the study?

The research study has been reviewed by Aston University's Ethics Committee.

Who do I contact if somethings goes wrong or I need further information?

Any further questions you have regarding this research study will be answered by Mr. Alex Ong Chee Horng, who is the study investigator. He can be contacted either via e-mail [redacted] or by phone [redacted] Alternatively, you may also contact either Dr. Leon Davies via e-mail [redacted] or Dr. Amy Sheppard via e-mail [redacted]

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

Should there be any question, concerns or complaint about how the study has been conducted, you can contact the Secretary of the University Research Ethics Committee either via e-mail at [redacted] or by telephone at [redacted]

Personal Identification Number for this study: ________________

VOLUNTEER CONSENT FORM

Title of Project:
Efficacy of Multifocal Soft Contact Lens on Asthenopic Orthophoric and Esophoric Myopes with Lag of Accommodation.

Research Venue:
[redacted]

Name of Chief Researcher:
Mr. Alex Ong Chee Horng

		Initial Box
1.	I confirm that I have read and understand the information sheet for the above study. 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 medical care or legal rights being affected.	
3	I agree to take part in the above study.	
4	I understand that I will receive a copy of this form.	

________________________ ________________________
Name of Subject Signature of Subject & Date

________________________ ________________________
Name of Person Obtaining Consent Forms Signature of Person & Date

1 Copy for research participant
1 copy for investigator

Appendix 4: Convergence Insufficient Symptom Survey Form

Convergence Insufficiency Symptom Survey

Name ____________________________________ DATE __/__/__

Clinician instructions: Read the following subject instructions and then each item exactly as written. If subject responds with "yes" - please qualify with frequency choices. **Do not give examples.**

Subject instructions: Please answer the following questions about how your eyes feel when reading or doing close work.

		Never	(not very often) Infrequently	Sometimes	Fairly often	Always
1.	Do your eyes feel tired when reading or doing close work?					
2.	Do your eyes feel uncomfortable when reading or doing close work?					
3.	Do you have headaches when reading or doing close work?					
4.	Do you feel sleepy when reading or doing close work?					
5.	Do you lose concentration when reading or doing close work?					
6.	Do you have trouble remembering what you have read?					
7.	Do you have double vision when reading or doing close work?					
8.	Do you see the words move, jump, swim or appear to float on the page when reading or doing close work?					
9.	Do you feel like you read slowly?					
10.	Do your eyes ever hurt when reading or doing close work?					
11.	Do your eyes ever feel sore when reading or doing close work?					
12.	Do you feel a "pulling" feeling around your eyes when reading or doing close work?					
13.	Do you notice the words blurring or coming in and out of focus when reading or doing close work?					
14.	Do you lose your place while reading or doing close work?					
15.	Do you have to re-read the same line of words when reading?					
		__x 0	__ x 1	__ x 2	__ x 3	__ x 4

TOTAL SCORE ___________

Appendix 5: Invitation and Explanation of Survey Purpose.

Google Forms

I've invited you to fill in a form:

Efficacy of Multifocal Soft Contact Lens on Asthenopic Orthophoric and Esophoric Myopes with Lag of Accommodation

Background:
This research study is for a Professional Doctorate conducted by Aston University, United Kingdom. This research study is organized by Mr. Alex Ong, who is a qualified optometrist practicing in Singapore and a student of Aston University, and supervised by Dr. Leon Davies (Reader and Director of Research) and Dr. Amy Sheppard (Lecturer and Director of the Professional Doctorate programme) also from Aston University. This research study is not being funded by any organisation.

Purpose:
The main objective of this survey is to better understand how optometrists in Singapore detect and diagnose visual fatigue symptoms, what treatment options they employ and the success rate (or not) of any treatment regimen.

Your identity in this study will be treated as private and confidential. All the data recorded will not contain any information that can directly identify you as a participant in the research study

Instruction:
Please help us by completing the following questions. Each question may either follow by a short answer or a choice of responses. Please response to the question to that corresponds to how you feel about each question and follow the instruction carefully. Once you have completed all the questions, please click the submit button at the end of the form.

Your participation is greatly appreciated.

FILL IN FORM

Create your own Google Form

Appendix 6: Sample of Google survey form used for the survey study

Efficacy of Multifocal Soft Contact Lens on Asthenopic Orthophoric and Esophoric Myopes with Lag of Accommodation

Background:
This research study is for a Professional Doctorate conducted by Aston University, United Kingdom. This research study is organized by Mr. Alex Ong, who is a qualified optometrist practicing in Singapore and a student of Aston University, and supervised by Dr. Leon Davies (Reader and Director of Research) and Dr. Amy Sheppard (Lecturer and Director of the Professional Doctorate programme) also from Aston University. This research study is not being funded by any organisation.

Purpose:
The main objective of this survey is to better understand how optometrists in Singapore detect and diagnose visual fatigue symptoms, what treatment options they employ and the success rate (or not) of any treatment regimen.

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Your participation is greatly appreciated.

*Required

Age *

Your answer

Sex *

- ◯ Male
- ◯ Female

Q1. How many years have you been practicing as an Optometrist? *

- ○ 1 - 5
- ○ 6 - 10
- ○ 11-15
- ○ 16 - 20
- ○ >21

Q2. Which of the following best describes your current practices? *

- ○ Private Practice
- ○ Hospital
- ○ Ophthalmologist Clinic
- ○ Institution
- ○ Other: ____________

Q3. During the course of your practice, do you see patients with ocular fatigue symptoms?

- ○ Yes (please proceed to Q4)
- ○ No (Please proceed to Q11)

Q4. On average, how many patients do you encounter with ocular fatigue in a month?

Your answer ____________

Q5. What is/are the symptom/s that patients present with when complaining of ocular fatigue?

Your answer

Q6. Do you use any form or questionnaire to determine the presence and/or severity of ocular fatigue?

- ◯ Yes (Please proceed to Q7)
- ◯ No (Please proceed to Q8)

Q7. What type of form(s) do you use? (Check all that apply)

- ◯ Convergence Insufficiency Symptoms Survey Form (CISS)
- ◯ College of Optometrists in Vision Development Quality of Life Assessment (COVD-QOL)
- ◯ Shorten COVD-QOL
- ◯ Other: ____________

Q8. Do you treat patients with ocular fatigue?

- ◯ Yes (Please proceed to Q9)
- ◯ No (Please proceed to Q11)

Q9. What kind of treatment (either optical devices or visual therapy technique) do you commonly prescribe to your patient with ocular fatigue symptoms at near?

Your answer

Q10. In general, how would you rate the success of the treatment regimen that you prescribe? (5 being most successful)

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5

Q11. Have you ever consider multifocal soft contact lenses as a treatment option for patients with symptoms of ocular fatigue at near? *

- ◯ Yes
- ◯ No

Q12. Why is that so? (Base on your response to Question 11) *

Your answer

SUBMIT

Never submit passwords through Google Forms.