Accommodative responses in non-Chinese adults, Chinese adults and Chinese children and their association with myopia development in Chinese children

by

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Certificate of originality

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Abstract

Introduction

Recent research findings suggested a link between nearwork and the onset, as well as development, of myopia. Extensive investigations on accommodative responses in different refractive groups have been carried out, but it remains unclear whether there are discrepancies in responses between groups. None of these previous studies compared responses in different ethnic groups using the same protocol, by the same examiner, an approach which may be illuminating, given the different prevalence rates for myopia between ethnic groups. In addition, recent technical advances allow the time patterns of accommodative responses, in particular nearwork-induced transient myopia (NITM), to be investigated.

Objectives

1. To investigate the amplitude of accommodation, accommodative stimulus-response curve, tonic accommodation and NITM in United Kingdom non-Chinese adults, Hong Kong Chinese adults and Hong Kong

Chinese children using the same protocol by the same examiner.

2. To compare these measures in myopic and emmetropic subjects.

3. To study the effect of race by comparing these measures between United Kingdom non-Chinese adults and Hong Kong Chinese adults.

4. To investigate the effect of age by comparing these measures between Hong Kong Chinese adults and children.

5. To determine any changes in these responses in Hong Kong Chinese children as myopia develops over one year.

Methods

A modified Shin-Nippon SRW-5000 auto-refractor (Shin-Nippon, Japan), an open-field instrument, was used to measure the accommodative responses in static or continuous modes as appropriate. Data collections for non-Chinese adults were carried out in the United Kingdom, while those for Chinese adults and children were carried out in Hong Kong.

Results

Chinese and non-Chinese adults gave similar amplitude of accommodation, tonic accommodation, accommodative response gradient and NITM results. Chinese adults had a gradient closer to unity and greater tonic accommodation as well as NITM (except NITM in the third 10-seconds post-change after the 5.0 D task), but lower amplitude of accommodation than children. There was no significant change in accommodative amplitude, gradient and NITM in children followed up longitudinally. Chinese myopic children showed an increase in tonic accommodation in the longitudinal study which was not related to their increase in myopia. There was no significant difference in amplitudes of accommodation, tonic accommodation, accommodative response gradient or NITM between myopes and emmetropes. The only difference was a greater accommodative amplitude in child emmetropes than myopes.

Conclusions

Chinese adults had similar amplitude of accommodation, accommodative response gradient, tonic accommodation and NITM with non-Chinese adults. Current findings indicated that the above accommodative functions were not factors explaining the higher prevalence of myopia found in Chinese. It is not clear if NITM is a factor causing the onset or progression of myopia as both refractive groups demonstrated similar amount of NITM after nearwork and the increase in myopia over time did not have any influence on NITM. The current results are different from previous findings in Chinese children, in which myopes were shown to have significantly greater NITM than emmetropes. The discrepancy in results between the current and previous studies in Chinese children could be due to the different age range of subjects recruited.

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Contents

Part II. Experiments

Part I. Background

Chapter 1. Introduction

Myopia is an alarming problem in Chinese due to its high prevalence of about 70 %, as reported by the studies in Hong Kong and China Mainland (Lam and Goh, 1991; Goh and Lam, 1994; Edwards, 1997; Edwards, 1999; He et al., 2004). The average annual incidence rate in Hong Kong preschool children from 2 to 6 years and schoolchildren from 6 to 17 years are about 8.2 % and 14 % respectively (Edwards, 1997; Lam et al., 1999; Fan et al., 2004a; Fan et al., 2004b). In sharp contrast to the above results, Mäntyjärvi (1983) reported an annual incidence of myopia of 2.6 % in their Finnish schoolchildren aged from 7 to 15 years.

The prevalence of myopia is greater in Chinese than non-Chinese. Lam and Goh (1991) found the prevalence increased from 30 % at age 6 to 7 years to 50 % and 70 % at age 16 to 17 years for Hong Kong Chinese girls and boys respectively. Later, Edwards (1997) obtained a similar trend, with the prevalence increasing from 11 % at age 7 years to 55 to 58 % at age 12 years. A higher prevalence was found by Lam and Goh (1991) probably because their study involved self-selection. The subjects in Edwards study originally joined a nutritional investigation and were asked to participate in her myopia research at a later time, and thus did not self-select for a myopia study. Recent studies (Fan et al., 2004a; Fan et al., 2004b) on Hong Kong preschool and schoolchildren reported similar findings with Lam and Goh (1999) that the prevalence increased from 4.6 % at age 2 to 6 years to 29 % at age 7 years and to 53 % at age 11 years or above. The prevalence of myopia in Guangzhou, China is also high. He et al. (2004) found an increase in prevalence from 3.3 % at age 5 years to 73 % at 15 years. In contrast, Laatikainen and Erkkia (1980) reported that the prevalence of myopia was only 1.9 % in their Finnish subjects at age 7 to 8 years and increased to 21.8 % at age of 14 to 15 years. There is also low prevalence of myopia in Indians, 3.19 % being reported in those aged under 15 years and 19.45 % in those above 15 years (Dandona et al., 2002). In Australians, the prevalence of myopia was found to be only 8.3 % at age 12 years (Junghans and Crewther, 2003). Zadnik et al. (2003) found the prevalence of myopia for American schoolchildren at age of 6 to 14 years was 11.6 %. A recent study (Quek et al., 2004) in Singapore high school students, aged 15 to 17 years, showed a greater prevalence of myopia in Chinese (77.1 %) than that in non-Chinese (consisted of Malays and

Indians) (68.2 %). Different definitions of myopia, selection of study population, age range of subjects, instruments used to measure myopia and use of cycloplegia employed in different studies may account for the differences in the prevalence of myopia (Saw, 2003).

The aetiology of myopia has been studied for many years. There appears to be some connection between myopia and prolonged close work though its exact nature is not clear (Rosenfield and Gilmartin, 1998; Goss, 2000; Zhao et al., 2000; Saw et al., 2001; Saw et al., 2002a; Saw et al., 2002c; Tong et al., 2002; He et al., 2004). The prevalence of myopia in subjects aged 5 to 15 years is higher in GuangZhou, an urban area (35.1 %) than those in ShunYi District, a rural area (16.2 %) of China. Children in these 2 places share the same ethnic origin, culture and language, but the former group have greater accommodative effort associated with schooling intensity than the latter group. Saw and her associates (Saw et al., 2001; Saw et al., 2002c) provided a strong evidence of the association between nearwork and myopia. They compared the prevalence of myopia, amount of nearwork and the time pattern for nearwork in China and Singapore Chinese children. Those who were living in Singapore (36.7 %) had the greatest prevalence of myopia, followed by those in Xiaman City (19 %) and those in Xiaman countryside (6.6 %) in China. The Singapore group spent the greatest amount of time in nearwork activity (reading, writing, playing video games and computer use), but the least in outdoor activity than the other groups. Playing video games and using computer were associated with the severity of astigmatism, where high AC/A ratio was associated with astigmatism (Tong et al., 2002). Astigmats were more likely to develop myopia then non-astigmats (Jiang, 1995; Mutti et al., 2000). Saw et al. (2002a) showed that the number of books read per week was associated with high myopia. They also found a stronger association between close work and myopia in Chinese than in non-Chinese. The putative link between myopia and close work has led to the notion that accommodation plays a role in the development and progression of myopia, and previous research has indeed shown differences in aspects of accommodation between myopes and non-myopes (Chapters 2 to 5).

Use of progressive lenses and pharmacological intervention (pirenzepine, for example) are two recent research directions for the control of myopia. Leung and Brown (1999) showed that progressive lenses (PAL) retarded myopia progression in Chinese children (aged 9 to 12 years) over 2-year and the effect was dose-related. Edwards et al. (2002) repeated Leung and Brown's experiment but in a larger scale and under well-controlled in children aged 7 to 10.5 years. They did not find any significant clinical effect over a 2-year period. Edwards and co-workers explained that the difference in these two studies might be due to the different age range and types of PAL used. The COMET study in North America (Gwiazda et al., 2004) found progressive lenses were effective in slowing the progression for children with greater lags and with near esophoria, shorter reading distances, more hours of near work or lower baseline myopia. This result is in accordance with that of Leung and Brown (2002). Both the COMET study and a Singapore study (Saw et al., 2000; Hyman et al., 2004) reported that the younger the children recruited at the beginning of the study, the greater the myopia progression would be.

Myopia progression and axial elongation in children can be controlled through pharmacological means such as topical atropine and pirenzepine (Chua et al., 2003; Siatkowski et al., 2003; Tan et al., 2003; Siatkowski et al., 2004). The rate of progression was retarded by about 0.95 D in a group of Singapore Children using 1 % Atropine once per night as compared with the control group (Chua et al., 2003). Pirenzepine is a relatively selective M_1 muscarinic antagonist (Saw et al., 2002b), which does not affect users' daily life much. It allows accommodation and normal function of the pupil. Tan et al. (2003) studied the effect of 2 % pirenzepine gel on Asian children, aged 6 to 12 years, for 1 year. There was a 50 % reduction in the progression of myopia in the treatment group as compared with the control group.

Animal studies in monkeys suggested that ocular growth and refractive development are mediated by optical defocus associated with the eye's effective refractive status (Smith III, 1998a; Smith III, 1998b; Smith III and Hung, 1999). Monkeys demonstrated recovery from experimentally induced refractive errors like negative-lens induced myopia. Moreover, changing the effective refractive status of the eye or the refractive balance between 2 eyes can alter the normal emmetropization in animals. Form deprivation myopia is axial in nature and is attributed primarily to an increase in vitreous chamber depth. It is the degradation of retinal image quality triggering form deprivation myopia, in which a greater amount of degradation leads to a greater degree of myopia (Smith III and Hung, 1995). Lag of accommodation in human could also be a form of deprivation that myopia developed as a result of chronic optical defocus/ blur during nearwork (Gwiazda et al., 1993). Accommodation is thus affecting the ocular growth in the way that it influences the retinal image quality.

This study will further exploring the accommodation characteristics in myopia, and in the following pages recent work on amplitude of accommodation, the accommodative stimulus-response curve, tonic accommodation and nearwork-induced transient myopia will be described.

Chapter 2. Amplitude of accommodation

Introduction

Amplitude of accommodation is perhaps the most basic measure of accommodation, and refers to the greatest amount of accommodation the eye can apply (Wold, 1967). A deficit in amplitude of accommodation (accommodative insufficiency), which means its value is lower than an individual's expected age norm, could lead to blurred vision at near (Wick and Hall, 1987). Due to the influence of convergence accommodation, binocular accommodative amplitude is higher than monocular amplitude (Wold, 1967; Otake et al., 1993; Chen and O'Leary, 1998). Previous investigators have used different methods to measure the accommodative amplitude and most focused on studying its relationship with age (Section 2.1 and Table 2.1). Relatively few have studied its relationship with refractive error (Section 2.2 and Table 2.2).

2.1. Effect of age

Donders was the first researcher to determine the amplitude of accommodation in different age groups (Duane, 1909). He used the push-up method and made measurement from the first nodal point of the eye. First blur point was used as the end point and a negative correlation was found between age and monocular accommodative amplitude. Duane (1909) supported Donders' findings showing that monocular accommodative amplitude declines with age, but the spectacle plane was set as the reference plane and still using the first blur point as the end point in his study. A thorough comparison of Donders' and Duane's results were made by Hofstetter (1944), who converted Donders' results from nodal point to spectacle plane and found that those aged below 20 years had higher accommodative amplitudes in Donders' experiment by 1.2 to 6.2 D. Hofstetter (1944) suggested the discrepancy was due to small subject numbers and poor accuracy in taking measurement in young children. An equation, based on Duane's data, was developed by Hofstetter, to calculate the minimum amplitude of accommodation:

$$\text{Amplitude of accommodation (D)} = 15 - (0.25) \times (\text{age})$$

Extensive work (Kragha, 1986; Woodruff, 1987; Kragha, 1989; Edwards et al., 1993; Atchison et al., 1994; Rosenfield and Cohen, 1996; Chen and O'Leary, 1998; Mordi and Ciuffreda, 1998; Chen et al., 2000) has been carried out in different populations, and results from major studies using the push-up method for subjects under 30 years old are listed in Table 2.1. Kragha (1989), Edwards et al. (1993), Atchison (1994); Mordi and Ciuffreda (1998) and Chen et al. (2000) all demonstrated a decrease in accommodative amplitude with age, and the amplitude of accommodation in Chinese was found to be lower than that in Caucasians of a similar age (Edwards et al., 1993). Most authors reported spectacle accommodation, while Edwards et al. (1993) described both spectacle and ocular accommodation in their study. Ocular accommodation is a better way of presenting accommodative amplitude as it considers the spectacle lens effectivity. Bennett and Rabetts (1984) demonstrated that for a given near point, a corrected myope accommodates less as compared with a corrected hyperope. Thus spectacle accommodation overestimates the accommodative amplitude of a myope and underestimates that of a hyperope.

2.2. Effect of refractive error

2.2.1. Adults

Fong (1997) demonstrated a lower accommodative amplitude in myopes compared with emmetropes (age from 26.3 to 27.2 years). He predicted that those with lower amplitude of accommodation would need to use more of their accommodation reserve for nearwork, and that myopia would eventually develop in order to lower the accommodative demand. However, most previous studies had reported that myopes had higher amplitudes of accommodation than emmetropes (Fledelius, 1981; Maddock et al., 1981). All subjects recruited in Fong's study were patients with diabetic retinopathy, and so his results might not reflect the situation in the normal individual.

As stated above, myopes exhibited higher amplitudes of accommodation than emmetropes in most studies, however, different subgroups of myopes gave different results. Maddock et al. (1981) reported that low myopes exhibited greater amplitude of accommodation than emmetropes, while high myopes did not (all subjects aged under 25 years). They could not explain this unexpected observation. For the subdivision of myopia according to the age of onset, McBrien and Millodot (1986a) reported a greater amplitude of accommodation in late-onset myopes (LOM) relative to early-onset myopes (EOM) and emmetropes (age between 18 and 22 years). Based on their findings, they concluded that LOM had a different cause than EOM. As parasympathetic innervation is responsible for an increase in accommodation, and sympathetic innvervation for a decrease in accommodation, they suggested that late-onset myopes have strong parasympathetic/ weak sympathetic innervation, leading to high accommodative amplitudes (Charman, 1982). The criterion used for determination of endpoint by McBrien and Millodot (1986a) was "blur to first clear", while others (see Table 2.2) used "clear to first blur". The former criterion tends to give lower accommodative amplitudes than the latter (Chen and O'Leary, 1998). Later, Malingre and Wildsoet (1995) lent support to McBrien and Millodot's finding that LOM have greater amplitude of accommodation than emmetropes, while EOM do not (subjects with age between 19 and 23 years). They suggested that myopes might have greater optical or neural depth of focus or increased perceptual blur threshold. The role of retinal blur can be identified upon the recent advances in the theoretical modelling of refractive error development (Flitcroft, 1998; Hung and Ciuffreda, 1999; Hung and Ciuffreda, 2000). Flitcroft (1998) proposed a model of emmetropization and myopia based on the interactions between accommodation and vergence and a mechanism of emmetropization driven by optical blur within the retinal image. The retinal image blur depends on the distance of the visual stimulus from the eye, the ocular accommodation state and the refractive error of the eye. Models developed by Hung and Ciuffreda demonstrated both genetic and defocus-induced environmental factors in the development of refractive error in different refractive groups (Hung and Ciuffreda, 1999; Hung and Ciuffreda, 2000). They found that the rate of ocular growth is dependant on the magnitude of the change in retinal defocus regardless of its direction of retinal blur. EOM exhibited both genetically-controlled and defocus-induced factors, while LOM underwent the latter factor only during the development of myopia.

In contrast, Fisher et al. (1987) did not find any significant difference in amplitude of accommodation between high myopes, low myopes, emmetropes and hyperopes (with age between 21 and 35 years). The discrepancy between Fisher et al. (1987) and Maddock et al. (1981) might be due to the different criteria used to differentiate emmetropes and high and low myopes. For example, some subjects classified as low myopes by Fisher et al. would have been classified as high myopes by Maddock et al. Maddock et al. admitted the criteria they used were arbitrary and were not set with consideration of issues related to aetiology of myopia.

2.2.2. Children

Only one study has tried to identify the association between refractive error and amplitude of accommodation in children. The findings of Wold (1967) did not agree with those obtained in the adult studies cited above. Wold found no difference in accommodative amplitudes in child myopes and hyperopes (with age between 6 to 10 years). However, the refractive range of his subjects was narrow, from – 1.50 D to + 2.00 D, and the author only grouped them into myopes and hyperopes. There was no categorization of emmetropes.

2.3. Summary

Findings of previous investigations are shown in Tables 2.1 and 2.2. Extensive work has been done to study the relationship between amplitude of accommodation and age and it is well known that amplitude of accommodation declines with age. However, very little is known regarding the effect of refractive error on amplitude of accommodation, especially in children. In general, while adult myopes demonstrate greater amplitude of accommodation than emmetropes, the only study on children observed similar accommodative amplitude in myopes and hyperopes. No previous investigation involved Chinese, a population with a high prevalence of myopia. It could be instructive to conduct a comprehensive investigation of amplitude of accommodation in different refractive groups in Chinese adults and children, and to compare their results with those from non-Chinese ethnicity. Further, no detailed study of the association between accommodative amplitude and change in refractive error in children has been carried out before.

Studies	Sample	Country of origin	Reference plane and end point used	Testing conditions	Amplitude of accommodation (D)
Rambo and Sangal (1960)	100 eyes (age range: 10 to 50 years) 15 age groups Age group of 20 years old	India	Spectacle, blur point	Monocular "cross mark" target push-up	8.23
	Age group of 25 years old				7.26
	Age group of 27.5 years old				6.29
Kragha (1986)	447 subjects (age range: 9 to 62 years) 5 age groups 21 to 25 years age group	Nigeria	Spectacle, blur point	Monocular letter target push-up	10.00
Woodruff (1987)	286 subjects (age range: 3 to 11 years) Age group of 9 years old	Canada	Spectacle, blur point	Monocular modified Sheard's method (Addition of minus lens in a phoropter)	13.20 ± 2.62
	Age group of 10 years old				13.70 ± 2.32
	Age group of 11 years old				11.95 ± 1.61
Kragha (1989)	488 eyes in 8 to 12 years age group	Nigeria	Spectacle, blur point	Monocular letter target push-up	12.66 ± 2.39
	2530 eyes in 18 to 22 years age group				10.38 ± 1.89
	2050 eyes in 23 to 27 years age group				9.36 ± 1.81
Edwards (1993)	121 subjects (age range: 11 to 65 years) Age group of 12.86 years old (n = 7)	Hong Kong, China	Spectacle, blur point	Monocular horizontal black line (0.30 LogMAR) push-up	12.54 ± 2.64
	Age group of 22.17 years old (n = 12)				10.60 ± 1.59
	Age group of 12.86 years old (n = 7)		Corneal, blur point		11.17 ± 1.39
	Age group of 22.17 years old (n = 12)				8.75 ± 1.02

Studies	Sample	Country of origin	Reference plane and end point used	Testing conditions	Amplitude of accommodation (D)
Atchison et al. (1994)	60 subjects (age range: 25 to 45 years) 25 to 29 age group	Australia	Spectacle, blur point	Monocular letter target push-up	8.00
Rosenfield and Cohen (1996)	13 subjects (age range: 23 to 29 years)	U.S.A.	Spectacle, blur point and recovery point	Monocular letter target push-up	10.11 ± 0.49 for blur point 9.50 ± 0.46 for recovery point
Chen and O' Leary (1998)	29 subjects (age range: 7 to 28 years)	Australia	Spectacle, blur point	Monocular push-up with RAF ruler	12.29 ± 2.41
Chen et al. (2000)	405 EMM (age range: 1 to 17 years) Mean age group of 11 years	Australia	Spectacle, recovery point	Monocular modified push-up with N8 LEA symbol target	11.00
	Mean age group of 12 years				10.50

Table 2.1. Results of accommodative amplitude studies in different age and population. EMM: Emmetropes.

Studies	Sample	Country of origin	Reference plane and end point used	Testing conditions	Amplitude of accommodation (D)
Wold (1967)	125 subjects (age range: 6 to 10 years) M, HYP (– 1.50 D to + 2.00 D)	U.S.A.	Spectacle, blur point	Binocular and monocular letter target push-up	M ≈ HYP under binocular and monocular conditions Binocular AA > Monocular AA
# Fledelius (1981)	137 subjects (mean age: 18 years) 52 EOM, 56 EMM, 29 HYP	Denmark	Corneal, blur point	Monocular push-up with RAF ruler	EOM (13.80) > EMM (11.60) > HYP (10.70) in the first visit
Gawron (1981)	144 subjects (age range: 17 to 28 years) 39 M (> – 1.00 D), 40 EMM (0.00 D to – 1.00 D), 65 HYP (≥ + 0.25 D)	Mexico	Unknown reference plane, blur point	Monocular or binocular was unknown, push-up with RAF ruler	M (11.88) ≈ EMM (10.62) > HYP (9.32)
Maddock et al. (1981)	Davis study 40 subjects (age under 25 years) 10 High M (> – 3.00 D), 10 Low M (< – 3.00 D), 20 EMM (no refractive correction)	U.S.A.	Corneal, blur point	Near acuity chart and a Laser Badal optometer	Low M (10.01) > EMM (7.00) High M (9.34) ≈ Low M High M ≈ EMM

Studies	Sample	Country of origin	Reference plane and end point used	Testing conditions	Amplitude of accommodation (D)
McBrien and Millodot (1986a)	80 subjects (age range: 18 – 22 years) 19 LOM (> 15 years onset), 23 EOM (< 13 years onset), 22 EMM, 16 HYP	Britain	Corneal, recovery point	Monocular letter target push-up	LOM (10.77) > EOM (9.87) > Emmetropes (9.28) > HYP (8.63)
Fisher et al. (1987)	48 subjects (age range: 21 to 35 years) 12 High M (> –4.00 D), 12 Low M (> –0.75 D but ≤ – 4.00 D), 12 EMM (± 0.75 D), 12 HYP (> +0.75 D)	U.S.A.	Corneal, blur point	Monocular letter target push-up in a Badal system	High M ≈ Low M ≈ EMM ≈ HYP
Malingre and Wildsoet (1995)	66 subjects (age range: 19 to 23 years) 19 LOM, 21 EOM, 26 EMM	Australia	Corneal, blur point	Monocular modified push-up	EOM > EMM LOM ≈ EOM LOM ≈ EMM Small but significant correlation between AA and refractive error
Fong (1997)	696 subjects (mean age: 26.3 to 27.2 years) 1148 M, 696 EMM (All were patients with diabetic retinopathy)	U.S.A.	Unknown	Unknown	M (4.03) < EMM (4.33)

Table 2.2. Results of accommodative amplitude studies as a function of refractive error. LOM: Late-onset myopes; EOM: Early-onset myopes, M: Myopes; EMM: Emmetropes, HYP: Hyperopes; AA: Amplitude of accommodation; #: Longitudinal study.

Chapter 3. The accommodative stimulus-response curve

Introduction

The accommodative stimulus-response curve describes the relationship between the static accommodative response and the stimulus in dioptric terms (Ciuffreda et al., 1984), and was first plotted by Morgan (1944). A typical stimulus-response curve of a typical corrected non-presbyope is S-shaped, with a central linear region, this region being studied the most (Charman, 1986). Lead of accommodation is found when the response is greater than the stimulus, particularly when looking at a far object, and lag of accommodation occurs when the response is less than the stimulus at near (Ramsdale and Charman, 1989).

An accommodative stimulus-response curve can be characterised by fitting a regression line along its central linear region. The gradient is widely used as an index for comparison between individuals. Chauhan and Charman (1995) proposed a new way to compare curves using an index called "accommodative error index". The accommodative error is the area bounded by the ideal 1:1 line and the regression line along the central region. The accommodative error index is the accommodative error divided by the square of the correlation coefficient. The accommodative error index has its drawback that it only describes the linear region of the response curve, while the non-linear region is ignored. A more recent and accurate method of comparing the curves was suggested by O'Donnell et al. (2003) and Jiang and O'Donnell (2004), that polynomial equation should be used and the gradient of the curve could be calculated from its derivation. For a more detailed explanation of this method, please refer to Section 7.4.2., Chapter 7.

Charman (1999) hypothesized a relationship between accommodative response gradient and myopia. He suggested a reduced gradient would lead to reduced modulation transfer (contrast of the image divided by contrast of the stimulus) for small details and one would have to bring the reading materials closer than normal so as to increase the detail subtense. However, closer working distance requires greater accommodation, and blur is then produced by the increase in accommodative lag. Charman suggested that repeated occurrence of such hyperopic blur would cause compensatory axial elongation and growth of myopia. The majority of studies showed late-onset and progressing myopes had greater accommodative lag and shallower accommodative response gradient than emmetropes, while stable myopes demonstrated similar accommodative responses with emmetropes (Table 3.1).

3.1. Adults

Using a laser optometer, Ramsdale (1985) compared the gradients of stimulus-response curves in myopes, hyperopes and emmetropes. Gradient and refractive error were poorly correlated and no statistically significant difference in accommodative responses was found between myopes and emmetropes. Support for these findings were provided by Tokoro (1988) and Hazel et al. (2003). Tokoro (1988) asked 16 subjects to fixate a target as it moved from 0.5 D to 5.0 D with a velocity of 0.25 D/ s, while Hazel et al. (2003) used a Maltese cross as a target and the negative lens series (NLS) method [a] to stimulate accommodative responses in 30 subjects. Speckle patterns were generated during rotation of a white rotatary drum in Ramsdale's set-up and cognitive and proximal factors in this target have been shown to contaminate the accommodative response (Post et al., 1984; Rosenfield et al., 1993). Further, as

[a] Negative lens series (NLS): Accommodative demand was increased by increasing the power of the negative lens used, while the subject maintained fixation at distant.

accommodative responses were measured under binocular condition, vergence accommodation would probably take place. Kim et al. (2001) and Nakatsuka et al. (2003) showed gradients of accommodative response curves of emmetropes and myopes were significantly steeper under binocular than under monocular conditions.

McBrien and Millodot (1986b) classified myopes into LOM and EOM and reported different results from Ramsdale (1985). Greater lag of accommodation was found with greater accommodative demand in all refractive groups (McBrien and Millodot, 1986b). They showed significant differences in accommodative responses between refractive groups at 4.0 D and 5.0 D demands, and LOM, but not EOM, having greater accommodative lag than emmetropes. LOM gave the shallowest gradient, followed by EOM, emmetropes and hyperopes. Gradients were found to significantly correlate with refractive error - the more negative the refractive error, the greater the lag. The authors suggested that differences in accommodative responses between groups were due to different autonomic innervation to ciliary muscle. A possible explanation for these findings is that LOM have stronger parasympathetic innervation than the other groups. Charman (1982) had previously pointed out that a weak sympathetic innervation would reduce the range of responses in the sympathetic part of the curve (see Figure 3.1.1.) and affect vision of more distant targets. This would make a subject relatively myopic as the weak sympathetic system is unable to sufficiently reduce the lens power to give a clear retinal image of a distant object. When the subject is fully corrected, tonic accommodation would be lower than that of an emmetrope having a normal balance between the sympathetic and parasympathetic system. McBrien and Millodot (1986b) predicted that all the accommodative responses on the curve, including tonic accommodation, would be shifted downward in LOM. However, LOM had been found to have greater accommodative amplitude than emmetropes in their other study (McBrien and Millodot, 1986a). If LOM had stronger parasympathetic innervation, they can exhibit greater accommodative response at near and their accommodative lag should be smaller than emmetropes. Explanations made by McBrien and Millodot supported their amplitude of accommodation results, but was contradictory to their accommodative-stimulus response findings.

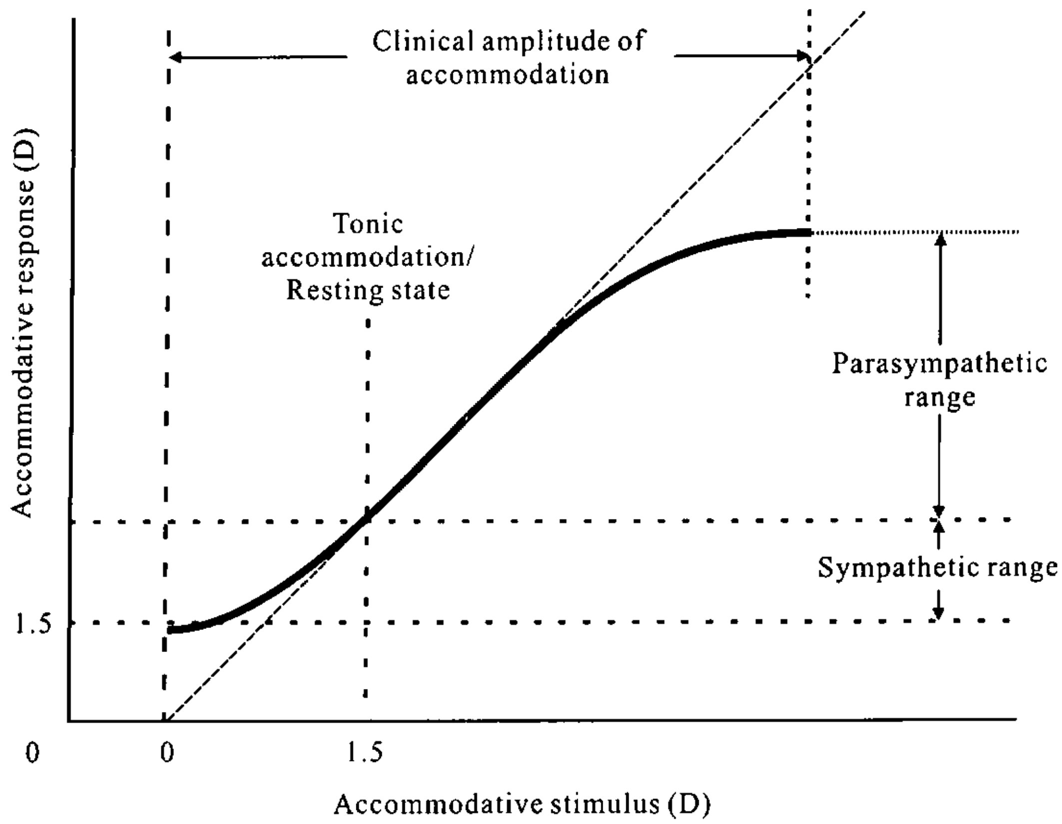

Figure 3.1.1. Typical accommodative stimulus-response curve (Charman, 1982).

Rosenfield and Gilmartin (1988a) and Jiang and White (1999) supported the findings of McBrien and Millodot (1986b) as they found a lower accommodative response in LOM, and Rosenfield and Gilmartin (1988a) suggested that the reduction in accommodative response at near for LOM under closed-loop conditions was due to greater disparity-induced accommodation in LOM than in emmetropes. McBrien and Millodot (1986b) did not carry out any statistical test to compare the accommodative response gradient in different groups. Although a significant correlation was reported between gradients and refractive error, the correlation showed only accounted for 25 % of the variance, so the clinical implication may be limited.

Abbott et al. (1998) measured the accommodative responses in young adults using 3 methods, namely decreasing distance series (DDS), negative lens series (NLS) and positive lens series (PLS) [b]. The first method, DDS, provided accommodative demand by altering the target distances in descending order, and was the most natural method as it stimulated normal visual situations. Abbott et al. determined the accommodative response gradient in myopes and emmetropes, with myopes classified into subgroups both according to the age of onset of myopia (LOM and EOM) and the history of myopic progression (progressing myopes, PM and stable myopes, SM). For the first classification, the accommodative response gradient of LOM, EOM and emmetropes were similar to each other in all methods. Results were different in the second classification, in which PM gave shallower gradient than SM and emmetropes and lower accommodative responses at higher accommodative demand (3.0 D and 4.0 D) in NLS, but not in DDS and PLS. Vera-Diaz et al. (2000) also showed a shallower

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[b] Positive lens series (PLS): Accommodative demand was increased by decreasing the power of positive lens used, while the subject maintained fixation at near.

gradient for PM as compared with SM and emmetropes. The above findings suggested accommodation insufficiency was related to progression of myopia, rather than age of onset. Unlike the findings of McBrien and Millodot (1986b), there was no significant correlation between refractive error and gradient obtained using DDS. Abbott et al. (1998) explained their contradictory correlation results compared with McBrien and Millodot (1986b) (although both adopted DDS) as being due to the recruitment of hyperopes in McBrien and Millodot's study while they did not. This suggested the correlation found in the latter study was due to difference in gradient between hyperopes and myopes, and not for different degrees of myopia.

Jiang (1997), Jiang and Morse (1999) and Chen (2002) used Badal systems to control the variation of target size and effect of proximity arising from the various distances used. All studies found myopes and emmetropes responded similarly to blur. Jiang (1997) suggested that the failure to show any significant discrepancy between refractive groups was because testing conditions utilizing good lighting and a target with high contrast and optimum spatial frequency might mask the effect. In addition, under these conditions, there was high accommodative sensory gain in subjects with different refractive errors (Hung and Semmlow, 1980; Jiang, 1997).

Nakatsuka et al. (2003) reported no statistically significant difference in accommodative response gradient between Japanese EOM and emmetropes under either monocular or binocular conditions. The correlation between gradient and refractive error was reported for only the latter condition and it was statistically insignificant. Their reported gradients for EOM and emmetropes were higher than those found by McBrien and Millodot (1986b). Although, McBrien and Millodot did not report the refractive errors of their subjects, the discrepancy between the findings of those two studies might be due to different ranges of refractive error and instruments used. Moreover, phenylephrine hydrochloride (a sympathomimetic mydriatric drug) which reduces the near point of accommodation due to vasoconstriction of ciliary blood vessels (Garner et al., 1983; Gilmartin, 1986) was used by McBrien and Millodot (1986b), therefore a lower accommodative response would occur, thus reducing the gradient.

3.2. Children

Gwiazda et al. (1993) studied the accommodative responses in children by DDS, NLS and PLS. They found children who had recently developed myopia showed lower accommodative responses at higher accommodative demand (3.0 D and 4.0 D) than emmetropes using the DDS method. The former group also had a shallower gradient (0.78) than the latter group (0.88). The difference was more prominent in NLS in that myopes gave consistently lower responses than emmetropes at 0.5 D to 4.0 D, with the gradient of the former group very much shallower (0.20) than the latter group (0.61). The situation was similar in adults and their accommodative responses were poorer under NLS than DDS and PLS (Abbott et al., 1998). The authors, however, could not differentiate differences in accommodative responses between EOM and emmetropes using PLS. The differences in accommodative responses between refractive groups are more easily picked up using the NLS method and this method is therefore more sensitive. It was because both refractive groups responded to proximity cues in DDS and had similar ability to relax accommodation. It appeared that the blur sensitivity in myopes was lower than that of emmetropes, as responses of myopes were mostly affected by negative lens-induced blur (Rosenfield and

Abraham-Cohen, 1999). Accommodative responses of children measured by Gwiazda et al. (1993) were much lower than those of adults as reported by Abbott et al. (1998). It seems that children are less sensitive to negative lens-induced blur than adults. Gwiazda et al. (1993) postulated that the blur induced by accommodation insufficiency in myopes would cause degradation in retinal image quality and lead to axial elongation as seen in animal models later (Norton and Siegwart, 1995; Wildsoet, 1997; Norton, 1999). They concluded that reduction in accommodation ability occurs before or shortly after the onset of myopia as their findings supported those for adults (McBrien and Millodot, 1986b) that myopes with recent onset have lower accommodative responses than emmetropes.

In a similar experiment, Gwiazda et al. (1995a) found a shallower gradient and lower range of accommodation in myopes relative to emmetropes. The gradients found in both groups were lower than previously found (Gwiazda et al., 1993), however, the authors explained that this was due to calculation of the gradient using different methods. The accommodative stimulus range was from 0.0 D to 4.0 D in Gwiazda et al. (1993), while that in Gwiazda et al. (1995a) was much wider, 0.0 D to 10.0 D. The calculation of slope in the former study was based on all points in the accommodative stimulus/response curve. However, in the latter study, four different types of calculation were done which varied in the number of points in the curves being counted. A statistically significant correlation was obtained between change in accommodative function and change in refractive error in myopes ($r = 0.77$, $p < 0.001$), but not in emmetropes. One of their emmetropic subjects who became myopic over 1 year (MSE increased by – 0.75 D) showed a reduced range of accommodation and accommodative responses after onset of myopia. This child had similar accommodative response functions as other emmetropic subjects before the onset of myopia, which suggested that loss of accommodative accuracy accompanies the development of myopia rather than is a precursor of it (Gwiazda et al., 1995a). Rosenfield et al. (2002) provided further evidence that a greater lag of accommodation was the consequence, but not the cause of myopia.

Both of the experiments conducted by Gwiazda and her colleagues recruited subjects of a wide age range (5 to 17 years) in Gwiazda et al. (1993) and 6 to 18 years in Gwiazda et al. (1995a), but they did not take into account the effect of age on accommodative response. Chen and O'Leary (2002) noted this problem and investigated the relationship between these 2 parameters in subjects aged between 3 and 14 years. No significant relationship was found between age and accommodative response gradient, between age and accommodative lead at distance or between age and accommodative lag at near. Subjects in studies by Gwiazda et al. (1993) and Gwiazda et al. (1995a) wore trial lenses or habitual corrections during the experiment, and it is possible that reflections from the lens affected measurement accuracy (Ong and Ciuffreda, 1997). Further, the authors estimated that there was a reduction of 5 to 6 % of accommodation due to the position of the lens with a forward tilt of 10 to 15 degrees. The situation also occurred in the Abbott et al. (1998) study as they followed the protocol of Gwiazda et al. Ong and Ciuffreda (1997) commented that this would create unwanted astigmatism and change in spherical power and lead to possible reduction in accommodative responses of newly myopic children.

Accommodative response can increase with increased proximity (proximal accommodation) (Wick and Currie, 1991). Target size would decrease with increasing minus lens power and thus its apparent position would be further away in NLS. Chen and O'Leary (2002) argued that the lower accommodative responses found in myopes by Gwiazda et al. (1993) was due to effects of proximity and size. However, proximity cues are not particularly relevant when the target stays at the same distance as in NLS and PLS. Moreover, monochromatic aberration was found to increase with increased accommodative stimulus produced by negative lens power, resulting in lag of accommodation (Collins, 2001; Hazel et al., 2003).

A recent study on Chinese children by Chen et al. (2003) measured the accommodative response at 0.0 D and 3.3 D demand (DDS method) and found both emmetropes and myopes had a similar lead of accommodation (emmetropes: 0.22 D; myopes: 0.19 D) at distance, and lag (emmetropes: 0.63 D; myopes: 0.45 D) at near. There was no significant difference in accommodative response (for either stimuli) between the 2 refractive groups.

3.3. Summary

The findings of previous investigations are shown in Table 3.1. Accommodative response gradient and lag are the two main aspects reported in the investigation of the accommodative response curve. Findings regarding the relationship between accommodative response gradient and refractive errors in adults showed late-onset and progressing myopes had greater accommodative lag and shallower gradient than emmetropes. Stable myopes, on the other hand, gave similar accommodative responses to emmetropes. In younger age groups, there were few studies reporting accommodative response gradient and they found that the gradient of myopes was flatter than emmetropes. Some studies on accommodative lag demonstrated greater lag in child myopes than emmetropes at high accommodative demand, while some did not.

Although cross-sectional and longitudinal studies of accommodative response curves in children and adults and of the effect of age on accommodative responses in both groups have been carried out, none of those studies investigated accommodative response curves in children and adults using the same protocol by the same examiner. The effect of inter-examiner variation, such as subject instructions, has to be considered in making comparison between groups (Winn et al., 1991; Chen and O'Leary, 2002).

Study	Sample	Refractive correction	Instrument	Target for accommodation	Results
Ramsdale (1985)	40 subjects (age range: 18 to 34 years) 15 M (– 0.50 D to – 7.75 D), 15 EMM (< ± 0.50 D), 10 HYP (+0.50 D to +5.50 D)	Trial lens	Laser optometer	Binocular, DDS: 0 D to 5 D Illiterate E changed in 0.50 D steps	Equations of regression lines: M: $y = 0.81x + 0.42$ EMM: $y = 0.87x + 0.38$ HYP: $y = 0.85x + 0.49$ Weak correlation between gradient and refractive error ($r = 0.32$, $p > 0.05$)
McBrien and Millodot (1986b)	40 subjects (age range: 18 to 23 years) 10 LOM (> 15 years onset), 10 EOM (<13 years onset), 10 EMM (– 0.25 D to + 0.74 D), 10 HYP	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Binocular, DDS: 0 D to 5 D reading print placed at 1/5 m, 1/4 m, 1/3 m, 1/2 m, 1 m, 2 m and 6 m	Equations of regression lines: LOM: $y = 0.87x - 0.06$ EOM: $y = 0.88x - 0.09$ EMM = $0.92x - 0.05$ HYP = $0.97x - 0.20$ Significant correlation between gradient and refractive error ($r = 0.50$, $p < 0.001$)
Ward and Charman (1987)	16 subjects (age range: 18 to 32 years) 8 M (– 0.30 D to – 3.00 D), 8 HYP (+ 0.25 D to + 1.00 D)	Trial lens	Open-field infra-red Canon R-1 auto-refractor	Monocular, NLS and PLS: – 1.5 D to 3 D, Landolt C placed at 6 m, lenses were added in 0.25 D or 0.50 D steps	No difference in AR between M and HYP

Study	Sample	Refractive correction	Instrument	Target for accommodation	Results
Tokoro (1988)	32 subjects (age range: 20 to 35 years) 16 M, 16 EMM	Unknown	Infra-red optometer	Cross target at 0.5 D on a moving system	AR of M = EMM
Bullimore et al. (1992)	28 subjects (age range: 19 to 23 years) 14 LOM (– 0.50 D to – 3.50 D), 14 EMM (0.00 D to – 0.50 D)	Soft contact lens	Modified open-field infra-red Canon R-1 auto-refractor	Binocular, DDS: 1 D to 5 D numbers	AR of LOM < EMM under passive condition AR of LOM = EMM under active condition
Gwiazda et al. (1993)	64 subjects (age range: 5 to 17 years) 16 M (> – 0.50 D), 48 EMM (–0.25 D to + 0.50 D)	Trial lens	Open-field infra-red Canon R-1 auto-refractor	Monocular, DDS: 0 D to 4 D 6/30 letters NLS: 0 D to 4 D 6/30 letters placed at 4 m with plano to – 4 D lenses added in 0.50 D steps PLS: 6/30 letters placed at 0.25 m with plano to + 4 D lenses added in 0.50 steps	AR of M < EMM at 3 D (2.00 D versus 2.33 D) and 4 D (2.95 D versus 3.34 D) in DDS and at 0.50 D to 4 D demands in NLS, M = EMM in PLS Gradient of M < EMM in DDS (0.78 versus 0.88) and NLS (0.20 versus 0.61), M = EMM in PLS

Study	Sample	Refractive correction	Instrument	Target for accommodation	Results
# Gwiazda et al. (1995a)	63 subjects (age range: 6 to 18 years) 23 M (– 0.38 D to – 5.25 D), 40 EMM (– 0.25 D to + 0.75 D) in the first visit	Habitual correction	Open-field infra-red Canon R-1 auto-refractor	Monocular, NLS: 0 D to 10 D, 6/30 letters placed at 4 m with lenses added in 0.50 steps up to – 6 D and in 1.0 steps thereafter	Gradient of M (0.50) < EMM (0.70) in the first visit Range of accommodation of M (4.7 D) < EMM (7.5 D) in the first visit Correlation between change in accommodation function and change in refractive error was significant for M (r = 0.77), but not for EMM (r = 0.09)
Jiang (1997)	23 subjects (mean age: 23.5 years) 10 LOM (– 0.50 D to – 2.13 D, > 15 years onset), 13 EMM (– 0.38 D to + 0.38 D)	Soft contact lens or trial lens	Open-field infra-red Canon R-1 auto-refractor	Monocular, DDS: 1 D to 4 D Maltese cross in a Badal stimulator	Gradient of LOM (0.83) ≈ EMM (0.90)

Study	Sample	Refractive correction	Instrument	Target for accommodation	Results
Abbott et al. (1998)	33 subjects (age range: 18 to 31 years) [12 LOM (> 15 years onset), 10 EOM (< 14 years onset)], OR [12 PM (myopia progresses over last 2 years), 10 SM (myopia stable over last 2 years)], 10 EMM (– 0.25 D to + 0.75 D)	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Monocular, DDS: 0 D to 4 D 6/9 letters NLS: 0 D to 4 D (1 D step) 6/9 letters placed at 4 m with plano to – 4 D lenses added in 1 D steps PLS: 6/9 letters placed at 0.25 m with + 4 D to plano lenses added in 1 D steps	Gradient of LOM = EOM = EMM in DDS, NLS and PLS No correlation between gradient and refractive error (r = 0.00, p = 0.96) in DDS AR of PM < SM and EMM in NLS, not for DDS or PLS Gradient of PM (0.70) < SM (0.85) and EMM (0.84) in NLS, not for DDS or PLS
Jiang and Morse (1999)	18 subjects (mean age: 24 years) 5 PM (– 0.50 D to – 3.00 D, myopia progresses over last 2 years), 5 SM (– 1.50 D to – 3.00 D, myopia stable over last 2 years), 8 EMM (– 0.38 D to + 0.25 D)	Soft contact lens or trial lens	Open-field infra-red Canon R-1 auto-refractor	Monocular DDS: 1 D to 5 D Maltese cross target in a Badal stimulator	Gradient of PM (0.76) = SM (0.68) = EMM (0.74)

Study	Sample	Refractive correction	Instrument	Target for accommodation	Results
Jiang and White (1999)	27 subjects (mean age: 23.6 years) 7 LOM (– 0.75 to – 3.50 D), 8 EMM (– 0.50 D to + 0.50 D)	Soft contact lens or trial lens	Open-field infra-red Canon R-1 auto-refractor	Monocular, DDS: 0.25 D to 6.00 D 6/30 Snellen E placed from 4.0 m to 0.17 m	Gradient of LOM (0.86) < EMM (0.96)
Vera-Diaz et al. (2000)	39 subjects (age range: 18 to 25 years) 11 PM, 14 SM, 14 EMM	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Monocular, Unknown method	Gradient of PM < SM and EMM
Chen (2002)	20 subjects (age range: 19 to 30 years) 10 M (– 1.00 D to – 8.00 D), 10 EMM (– 0.50 D to + 0.75 D)	Trial lens	Open-field infra-red Canon R-1 auto-refractor	Monocular, DDS: 0 D to 4 D presented through a Badal system	AR of M = EMM Equations of regression lines: M: $y = 0.60x + 0.89$ EMM: $y = 0.68x + 0.86$

Study	Sample	Refractive correction	Instrument	Target for accommodation	Results
Chen and O'Leary (2002)	118 subjects (age range: 3 to 14 years) 4 age groups (1 year in one age-group), age groups other than 9-12 years were excluded	Unknown	Open-field infra-red Canon R-1 auto-refractor	Monocular, DDS: 0 D to 4 D 6/24 picture target placed at 5 distances	Equations of regression lines in different age groups: 9: y = 0.92x –0.01 10: y = 0.92x – 0.04 11: y = 0.90x – 0.06 12: y = 0.94x – 0.12 Gradient was independent of age
# Rosenfield et al. (2002)	23 subjects (age range: 21 to 27 years) 7 M (> – 0.25 D), 15 EMM (– 0.25 D to + 0.50 D), 1 HYP (> + 0.50 D) in the first visit	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Binocular, DDS: 2.5 D to 5 D Snellen letters placed at 0.4 m, 0.33 m, 0.25 m and 0.20 m	No correlation between gradient and change in refractive error
	22 subjects (age range: 21 to 27 years) 7 EMM_EMM (+ 0.03 D) 8 EMM_M (– 0.02 D) 7 M (– 2.86 D) in the first visit (4 visits over 1 year)				Gradient (mean calculated from 4 visits) of EMM_M (1.02) ≈ EMM_EMM (0.99) > M (0.87) Gradients of all groups did not change over time

Study	Sample	Refractive correction	Instrument	Target for accommodation	Results
Chen et al. (2003)	30 subjects (age range: 8 to 12 years) 15 PM (> – 0.75 D, progressed > – 0.75 D), 5 SM (> – 0.75 D, progressed < – 0.50 D), 10 EMM (– 0.20 D to + 0.50 D)	Trial lens	Open-field infra-red Shin-Nippon SRW-5000 auto-refractor	Binocular, 0 D and 3.33 D letter/ number target placed at 6 m and 0.33 m	AR at 0 D of PM = SM = EMM AR at 3.33 D of PM = SM = EMM
Hazel et al. (2003)	30 subjects (age range: 18 to 27 years) 20 M (– 0.75 D to – 6.00 D), 10 EMM (0.00 D to + 0.25 D)	Soft contact lens	Open-field infra-red Shin-Nippon SRW-5000	Monocular, NLS: 0 D to 4 D (1 D step) black Maltese cross (equivalent to 6/9 Snellen letter) placed at 4 m	AR of M = EMM

Study	Sample	Refractive correction	Instrument	Target for accommodation	Results
Nakatsuka et al. (2003)	43 subjects (mean age: 26.8 for EOM, 27 for EMM) 15 EOM (< 15 years onset; – 1:00 D to – 5.90 D), 28 EMM (0.00 D to < – 1.00 D)	Habitual correction	Open-field infra-red Grand Seiko WV-500 auto-refractor	Binocular and Monocular, DDS: 1.98 D to 6.24 D Maltese cross placed at 0.51 m, 0.33 m, 0.21 m and 0.16 m	AR of EOM > EMM under binocular and monocular conditions Gradient of EOM = EMM under both binocular and monocular conditions Equations of regression lines: (Monocular): EOM: $y = 0.95x - 0.21$ EMM: $y = 0.95x - 0.33$ (Binocular) EOM: $y = 1.03x - 0.27$ EMM: $y = 1.03x - 0.44$ Weak correlation between gradient and refractive error under binocular condition

Table 3.1. Results of accommodative stimulus-response function studies as a function of refractive error and age. AR: Accommodative response; M: Myopes; EMM: Emmetropes; HYP: Hyperopes; LOM: Late-onset myopes; EOM: Early-onset myopes; PM: Progressing myopes; SM: Stable myopes; EMM_M: Emmetropes who became myopic; EMM_EMM: Emmetropes who remained emmetropic; DDS: Decreasing distance series; NLS: Negative lens series; PLS: Positive lens series; #: Longitudinal study.

Chapter 4. Tonic accommodation

Introduction

Tonic accommodation is a stimulus-free condition in which the eye adopts an intermediate dioptric position in the absence of visual stimulation such as a visual target, blur, disparity and proximal stimuli (Leibowitz and Owens, 1975; Fisher et al., 1990; Rosenfield et al., 1993). An individual with low tonic accommodation would theoretically have to exert greater parasympathetic effort to focus on a near target than one with high tonic accommodation (Strang et al., 1994; Jiang, 1995). Variation in parasympathetic innervation has been shown to give a much greater contribution to the variation in tonic accommodation than variation in sympathetic innvervation (Gilmartin et al., 1984; Gilmartin and Hogan, 1985). Previous studies gave contradictory results regarding the association of tonic accommodation and refractive error. Some studies found that myopes exhibited lower tonic accommodation than emmetropes (Table 4.1), while others showed no difference between groups.

4.1. Adults

In this section, tonic accommodation measured mainly by laser optometer will be detailed in the first paragraph, while that by infra-red optometer and advanced technology will be discussed in the remaining paragraphs.

Maddock et al. (1981) carried out 2 separate studies of tonic accommodation in Cardiff, Wales and Davis, California. The former study did not find any difference in tonic accommodation among emmetropes, myopes and hyperopes, while the latter study showed high myopes with the lowest tonic accommodation followed by emmetropes and low myopes. The authors suggested that the discrepancy was due to small sample size in both studies and, perhaps significantly in relation to the present study, recruitment of different racial groups. The study in Davis established a negative correlation between duration of myopia and tonic accommodation ($r = -0.53$) so that the longer the myopia had been present, the less the tonic accommodation. Both studies used a laser optometer to measure accommodative response, but the latter did not specify the experimental conditions. Unfortunately, the subject recruitment criteria used in those 2 studies were different, with a wider range of refractive error for emmetropes in the Cardiff study (± 2.00 D) which included low myopes and hyperopes. Ramsdale (1985) also found similar tonic accommodation in myopes and emmetropes using a laser optometer, tonic accommodation being unaffected by ametropia. The letter target used in Ramsdale's experiment was inappropriate for stimulating tonic accommodation, in which the absence of any fine stimulus is required. In addition, mental effort is required to judge the direction of the speckle pattern in laser optometry and this has been shown to increase the accommodative response (Post et al., 1984). Bullimore and Gilmartin (1987) found similar tonic accommodation in myopes and emmetropes under active conditions (a counting task with mental effort), while myopes had lower tonic accommodation than emmetropes under passive conditions (simple fixation without mental effort).

A subsequent study by McBrien and Millodot (1987) reported lower tonic accommodation in LOM than emmetropes and EOM. They suggested the variation in tonic accommodation between refractive groups was due to different parasympathetic and sympathetic innervation to the ciliary muscle, LOM having both lower parasympathetic and sympathetic innervation as compared with the others. Rosenfield and Gilmartin (1987b) provided further evidence that their

LOM had lower tonic accommodation relative to emmetropes, but not to EOM. The values of tonic accommodation obtained by McBrien and Millodot (1987) and by Rosenfield and Gilmartin (1987a) were lower than those reported by Maddock et al. (1981). All these studies used an infra-red auto-refractor, which uses invisible infra-red light, to measure accommodative response. This does not call for subjective judgment and is therefore more appropriate for measuring tonic accommodation (Rosenfield et al., 1993). Tonic accommodation as measured by Maddock et al. (1981) might be contaminated by stimulation of speckle motion using laser optometry. However, with the use of an open-field infra-red optometer, Rosenfield and Gilmartin (1988b), Strang et al. (1994), Jiang (1997) and Jiang and White (1999) still could not observe any significant difference in tonic accommodation between LOM and emmetropes or between emmetropes, high and low myopes (Fisher et al., 1987). Strang et al. (2000) provided further evidence that tonic accommodation was independent of refractive error under various conditions (darkness, use of pinhole and bright field), though the obtained values varied from method to method.

Advances in technology allowed Rosenfield and Gilmartin (1989), Morse and Smith (1993) and Woung et al. (1993) to measure tonic accommodation continuously using a modified Canon R-1 infra-red optometer, an SRI optometer (SRI International) and a Nidek AR-1100 infra-red optometer respectively and all demonstrated that tonic accommodation appeared to be independent of refractive condition. Adams and McBrien (1993) also measured accommodative response in continuous mode with the use of a modified open-field infra-red Canon R-1 auto-refractor, with different results. Tonic accommodation was found to be lower in myopes relative to emmetropes. Almost half of their emmetropes became myopic over the 2-year longitudinal study period and experienced a significant drop in tonic accommodation. However, before the onset of their myopia, they had similar initial tonic accommodation with those who remained emmetropic over the study. These authors agreed with Gwiazda et al. (1993), who undertook a longitudinal study of accommodative response curve, that lower tonic accommodation was a consequence, but not a cause of myopia. Tonic accommodation reduces with age (Ramsdale and Charman, 1989; Mordi and Ciuffreda, 1998) and the age range of Adams and McBrien (1993) (21 to 55 years) was sufficiently wide that the aging effect would probably have influenced the results.

Jiang (1995) also demonstrated a reduced tonic accommodation after the onset of myopia, however, these newly developed myopes had higher initial tonic accommodation than those who remained emmetropic. This high level of tonic accommodation was therefore considered by Jiang as a precursor of myopia. Zadnik et al. (1999) hypothesized that upon development of myopia expansion of the eyeball would cause an increase in the tension of the ciliary muscle, which then stretched and flattened the crystalline lens, thus lowering tonic accommodation. However, Zadnik et al. (1999) commented that Jiang's results were inconclusive due to absence of correction for multiple comparisons, in other words, their probability values were spuriously low. Jiang and Morse (1999) and Vera-Diaz et al. (2000) demonstrated PM had higher tonic accommodation than SM and emmetropes, providing further evidence that elevated tonic accommodation occurs during myopia progression. Jiang and Morse (1999) proposed that an increased in tonic level would help to reduce accommodative lag at near, and hence influence the oculomotor system to stimulate changes in the characteristics of the eye.

Findings of older studies by Gawron (1981) and Tokoro (1988) were different to those obtained more recently, the former revealing a higher tonic accommodation in myopes as compared with emmetropes. Tokoro (1988) concluded that high tonic accommodation was a causal factor for myopia progression. Their different findings may have been due to use of a different target and measuring techniques, as these were not described by Gawron (1981). In addition, Tokoro (1988) presented a moving target that would have stimulated the subject's mental effort thus influencing the results (Bullimore and Gilmartin, 1987).

4.2. Children

Rosner and Rosner (1989) were the first to study tonic accommodation in children using methods other than near retinoscopy, i.e. dynamic retinoscopy with Difference of Gaussian (DOG) target. They found that myopes exhibited the lowest tonic accommodation and hyperopes the highest, with emmetropes in between. The trend was the same as in the adult findings reported in the Davis study of Maddock et al. (1981). Rosenfield et al. (1994) observed no difference in tonic accommodation between children and young adults. Rosner and Rosner (1989) supported van Alphen's proposition that children with low ciliary muscle tone (low tonic accommodation) were more susceptible to myopia (van Alphen, 1961), however, the accuracy of their technique was doubtful, and even the authors themselves admitted that they did not consider inter-examiner variability or control examiner bias. Later, Gwiazda et al. (1995b) showed the same trend as that reported by Rosner and Rosner (1989) but their mean values for tonic accommodation were lower. This may be due to the different methodology used to measure accommodative response in the 2 studies.

All the studies mentioned so far were carried out in Caucasians and study of a population, such as Chinese, with a high prevalence of myopia may be illuminating. Woung et al. (1998) have measured the tonic accommodation among Taiwan school children. Their myopes had lower tonic accommodation than emmetropes, agreeing with the findings of Rosner and Rosner (1989) and Gwiazda et al. (1995b). Chat (2001) measured tonic accommodation in a group of Hong Kong Chinese children having a lower age range than that in the study by Woung et al. (1998) and she also found lower tonic accommodation in myopes relative to emmetropes and hyperopes. Myopes may have lower tonic accommodation as they undergo an overall decrease in autonomic innvervation, which might be related to the stress induced in school (Woung et al., 1998). A low tonic accommodation may then be a predisposing factor for the onset of myopia.

Wolffsohn et al. (2003) (including the present author), however, found different results from the previously cited studies. They used a modified infra-red auto-refractor, which could measure accommodative response continuously, and a 0.1 cpd DOG target, reporting a similar tonic accommodation between EOM and emmetropes. The difference between Wolffsohn et al. and other studies might be due to the use of different instrumentation and targets. On the other hand, subjects recruited in Chat's study were much younger than those by Wolffsohn et al., this might also be one of the factors leading to the difference found.

Zadnik et al. (1999) did not provide support that low tonic accommodation was a predisposing factor for the onset of myopia in their longitudinal study of tonic accommodation in children. They compared the tonic accommodation of myopic, emmetropic and hyperopic subjects under 2 different conditions, namely lit empty field and dark field with a fixation light. Tonic accommodation was found to decrease with an increase in age and to be lower under dark field than lit empty field conditions within the age range of 6 to 11 years. Myopes experienced significantly lower values of tonic accommodation than emmetropes in both conditions over the 4-year investigation. The initial tonic accommodation for emmetropes who developed myopia and those who remained emmetropic were the same. The failure to show that children with low tonic accommodation were at higher risk to develop myopia led them to conclude that low tonic accommodation was a consequence, but not a predictor of myopia. The findings of Gwiazda et al. (1997) and Yap et al. (1998) were similar to those of Zadnik et al. (1999). Gwiazda et al. (1997) also carried out a longitudinal study and observed similar tonic accommodation in those newly developed myopes and remaining emmetropes over a period of 6 to 18 months. Reduction of tonic accommodation in myopes did not appear after the onset of myopia. Yap et al. (1998) demonstrated myopes had lower tonic accommodation than hyperopes and emmetropes in Nepal. Seventy-five emmetropes were followed for 2 years and the 8 who became myopic did not demonstrate a significant correlation between initial tonic accommodation and change in refractive error.

4.3. Summary

Findings of previous investigations are shown in Table 4.1. Results in regard to refractive groups from both adults and children have been equivocal, and comparisons have not been aided by the different methodologies used. Previous cross-sectional studies reported similar tonic accommodation between myopes and emmetropes or lower tonic accommodation was found in myopes in adults. Children who were myopic had lower tonic accommodation than those who were emmetropic. Longitudinal studies of previously emmetropic subjects generally found no difference in initial tonic accommodation in either subjects who remained emmetropic or in those who developed myopia. Low tonic accommodation could therefore be an outcome, rather than a predictor of myopia. In addition, although tonic accommodation was found to reduce with age, young adults had similar tonic accommodation as children in the studies by Rosenfield et al. (1994). Therefore, it seems that children and young adults have similar tonic accommodation.

Very few studies were based on a population with a high prevalence of myopia. The aetiology of myopia may be different in different racial groups (Woung et al., 1993) and it is clear that the recent increase in prevalence of myopia in Hong Kong Chinese is environmental rather than genetic in origin (Wu and Edwards, 1999). It is worthwhile investigating the role of tonic accommodation in Chinese myopes as well as its change upon myopia progression.

Studies	Sample	Refractive correction	Instrument	Testing conditions	Results (D)
Gawron (1981)	144 subjects (age range: 17 to 28 years) 39 M (> – 1.00 D), 40 EMM (0.00 D to – 1.00 D), 65 HYP (≥ + 0.25 D)	Nil	Polarized vernier optometer	Unknown	TA of M (3.37 ± 1.48) > EMM (0.90 ± 0.57) > H (0.28 ± 0.62)
Maddock et al. (1981)	Cardiff, U.K. study 23 subjects (age under 25 years) 9 M (–2.00 to – 7.00 D), 9 EMM (± 2.00 D), 5 HYP (+ 2.00 D to +4.00 D)	Unknown	Laser optometer	Complete darkness	TA of HYP (1.30) ≈ ĒMM (0.96) ≈ M (0.74)
	Davis, U.S.A. study 40 subjects (age under 25 years) 10 High M (> – 3.00 D), 10 Low M (< – 3.00 D), 20 EMM (no refractive correction)			Unknown	TA of high M (0.94) < EMM (1.62) and Low M (1.54)

Studies	Sample	Refractive correction	Instrument	Testing conditions	Results (D)
Ramsdale (1985)	40 subjects (age range: 18 to 34 years) 15 M (– 0.50 D to – 7.75 D), 15 EMM (+ 0.50 D to – 0.50 D), 10 HYP (+ 0.50 D to +5.50 D)	Trial lens	Laser optometer	6/3 to 6/19 Snellen E under dim illumination ($6cd/m^2$)	TA of M (1.63) ≈ EMM (2.85) ≈ HYP (3.48) No correlation between TA and refractive error
Bullimore and Gilmartin (1987)	30 subjects (age range: 19 to 26 years) 15 LOM (–0.50 D to – 3.50 D, > 15 years onset), 15 EMM (0.00 D to +0.50 D)	Nil	Open-field infra-red Canon R-1 auto-refractor	Darkness, counting task under active condition (required cognitive effort)	TA of LOM (0.81) < EMM (1.14) under passive condition TA of LOM (1.16) ≈ EMM (1.21) under active condition
Fisher et al. (1987)	48 subjects (age range: 21 to 35 years) 12 High M (> – 4.00 D), 12 Low M (> – 0.75 D but ≤ – 4.0 D), 12 EMM (± 0.75 D), 12 HYP (> +0.75 D)	Trial lens	Hartinger coincidence optometer	Optometer target in darkness	TA of High M (2.00) ≈ Low M (1.00) ≈ EMM (2.00) ≈ HYP (1.57)

Studies	Sample	Refractive correction	Instrument	Testing conditions	Results (D)
McBrien and Millodot (1987)	62 subjects (age range: 19 to 25 years) 15 LOM, 15 EOM, 17 EMM, 15 HYP	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Complete darkness for 12 min.	TA of LOM (0.49) < EMM (0.89), EOM (0.92) < HYP (1.33) Weak correlation between TA and ocular refraction (r = 0.24)
Rosenfield and Gilmartin (1987a)	51 subjects (mean age: 21 years) 17 LOM (> −0.50 D, > 15 years onset), 17 EOM (> − 0.50 D, < 15 years onset), 17 EMM (± 0.50 D)	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Complete darkness for 5 min.	TA of LOM (0.31) < EMM (0.75) TA of EOM (0.46) ≈ LOM, EOM ≈ EMM
Rosenfield and Gilmartin (1988b)	20 subjects (mean age: 21 years) 10 LOM (− 0.75 D to − 4.00 D), 10 EMM (± 0.50 D)	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of LOM (0.49) ≈ EMM (0.61)
Tokoro (1988)	32 subjects (age range: 20 to 35 years) 16 M, 16 EMM	Unknown	Infra-red optometer	Cross target at 0.5 D on a moving system	TA of M (0.18) > EMM (− 0.06)

Studies	Sample	Refractive correction	Instrument	Testing conditions	Results (D)
Rosenfield and Gilmartin (1989)	20 subjects (mean age: 22 years) 10 LOM (– 2.30 D), 10 EMM (– 0.02 D)	Soft contact lens	Modified Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of LOM (0.71) ≈ EMM (0.42)
Rosner and Rosner (1989)	113 subjects (age range: 6 to 14) 33 M (> – 0.25 D), 61 EMM (– 0.25 D to + 0.75 D), 19 HYP (> +0.75 D)	Trial lens	Dynamic retinoscopy	0.2 cpd DOG target under dim illumination	TA of M (1.36) < EMM (1.54) < HYP (1.73)
Hung and Ciuffreda (1991)	48 subjects (age range: 21 to 35 years) High M (> –4.00 D), Low M (– 0.75 D to – 4.00 D), EMM (± 0.75 D), HYP (> +0.75 D)	Trial lens	Hartinger coincidence optometer	Optometer target in darkness	TA of high M (1.85) and EMM (1.89) > HYP (1.57) and Low M (1.10)
#Adams and McBrien (1993)	164 subjects (age range: 21 to 55 years) 117 M, 47 EMM	Unknown	Modified open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of M (0.60) < EMM (0.90) in the first visit No difference in initial TA between EMM_EMM and EMM_M ↓ in TA after onset of myopia in EMM_M

Studies	**Sample**	**Refractive correction**	**Instrument**	**Testing conditions**	**Results (D)**
Morse and Smith (1993)	28 subjects (age range: unknown) 10 LOM, 9 EOM, 9 EMM	Unknown	SRI optometer	Unknown	TA of LOM ≈ EOM ≈ EMM
Woung et al. (1993)	51 subjects (age range: 19 to 38 years) 15 LOM (> – 0.50 D, > 15 years onset), 18 EOM (> – 0.50 D, < 14 years onset), 18 EMM (– 0.25 D to + 0.75 D)	Unknown	Nidek AR-1100 infra-red refractometer	Blurred internal asterisk-shaped target placed 8 D in front of far point (Bright empty field)	TA of LOM (0.59) ≈ EOM (0.65) ≈ EMM (0.79)
Rosenfield et al. (1994)	10 children (age range: 5 to 13 years), 10 adults (age range: 22 to 30 years)	Habitual correction	Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of children (1.01) ≈ adults (0.88)
Strang et al. (1994)	20 subjects (mean age: 22.4 years) 10 LOM (– 1.00 D to – 3.25 D, > 15 years onset), 10 EMM (– 0.25 D to + 0.50 D)	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of LOM (0.90) ≈ EMM (0.86)

Studies	Sample	Refractive correction	Instrument	Testing conditions	Results (D)
Gwiazda et al. (1995b)	87 subjects (age range: 6.5 to 16.5 years) 18 EOM (– 0.25 D to – 7.00 D), 57 EMM (– 0.25 D to + 0.75 D), 12 HYP (+1.00 D to + 4.12 D)	Trial lens	Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of EOM (0.30) < EMM (0.75) < HYP (0.94)
# Jiang (1995)	44 subjects (age range: 18 to 27 years), 6 were excluded 7 LOM (– 0.37 D to – 1.75 D), 25 EMM (– 0.25 D to + 0.37 D), 6 pre-onset group (Emmetropes who became myopic over 2 to 3 years)	Unknown	Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of LOM (0.44) < EMM (0.88) < Pre-onset group (1.24) in the first visit ↑ in myopia → ↓ in TA Initial TA of EMM_M > EMM_EMM
Jiang (1997)	23 subjects (mean age: 23.5 years) 10 LOM (– 0.50 D to – 2.13 D, > 15 years onset), 13 EMM (– 0.38 D to + 0.38 D)	Soft contact lens or trial lens	Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of LOM (0.63) ≈ EMM (0.99)

Studies	Sample	Refractive correction	Instrument	Testing conditions	Results (D)
# Gwiazda et al. (1997)	70 subjects (mean age: 10 years) 16 EMM_M, 54 EMM_EMM	Unknown	Open-field infra-red Canon R-1 auto-refractor	Unknown	TA of EMM_M (0.33) ≈ EMM_EMM (0.48) in the first visit
# Yap et al. (1998)	210 subjects (age range: 7 to 16 years) 77 M (> – 0.50 D), 110 EMM (– 0.50 D to +0.75 D), 23 HYP (> + 0.75 D)	Unknown	Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of M (0.44) < EMM (0.69), M < HYP (0.67) in the first visit No correlation between change in refractive error and initial TA
Woung et al. (1998)	34 subjects (age range: 7 to 12 years) 19 EOM (– 1.25 D to – 5.25 D), 15 EMM (– 0.25 to + 0.75 D)	Nil	Nidek AA-2000 infra-red optometer	Blurred internal asterisk-shaped target placed 8 D in front of far point (Bright empty field)	TA of EOM (1.03) < EMM (1.37)

Studies	Sample	Refractive correction	Instrument	Testing conditions	Results (D)
Jiang and Morse (1999)	18 subjects (mean age: 24 years) 5 PM (– 0.50 D to – 3.00 D, myopia progresses over last 2 years), 5 SM (– 1.5 D to – 3.00 D, myopia stable over last 2 years), 8 EMM (– 0.38 D to + 0.25 D)	Soft contact lens or trial lens	Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of PM (2.29) > SM (0.53), PM > EMM (0.65)
Jiang and White (1999)	27 subjects (mean age: 23.5 years) 7 LOM (– 0.75 to – 3.50 D), 8 EMM (– 0.50 D to + 0.50 D)	Soft contact lens or trial lens	Open-field infra-red Canon R-1 auto-refractor	Complete darkness	TA of LOM (0.68) ≈ EMM (0.75)
# Zadnik et al. (1999)	790 subjects (age range: 6 to 15 years) in final visit EOM (> – 0.75 D), EMM (– 0.75 D to + 1.00 D), HYP (> + 1.00 D)	Unknown	Open-field infra-red Canon R-1 auto-refractor	Lit empty field	TA of EOM (0.79) < EMM (1.92) < HYP (2.46) in final visit
				Dark field with fixation light	TA of EOM (1.07) < EMM (1.70) and HYP (1.63) in final visit

Studies	Sample	Refractive correction	Instrument	Testing conditions	Results (D)
Strang et al. (2000)	164 subjects (mean age: 21.5 years) 50 LOM (≥ – 0.50 D, > 15 years onset), 51 EOM (≥ – 0.50 D, < 15 years onset, 63 EMM (– 0.25 D to + 0.50 D)	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Complete darkness/ pinhole	Complete darkness TA of LOM (0.65) ≈ EOM (0.77) ≈ EMM (0.73) Pinhole TA of LOM (1.27) ≈ EOM (1.42) ≈ EMM (1.62)
	60 subjects (mean age: 22 years) 20 LOM (≥ – 0.50 D, > 15 years onset), 20 EOM (≥ – 0.50 D, < 15 years onset, 20 EMM (– 0.25 D to + 0.50 D)			Complete darkness/ Bright field	Complete darkness TA of LOM (1.31) ≈ EOM (1.38) ≈ EMM (1.31) Bright field TA of LOM (1.46) ≈ EOM (1.15) ≈ EMM (1.15)
Vera-Diaz et al. (2000)	39 subjects (age range: 18 to 25 years) 11 PM (myopia progressed > – 0.50 D over 2 years), 14 SM, 14 EMM	Soft contact lens	Open-field infra-red Canon R-1 auto-refractor	Unknown	TA of PM and EMM > SM

Studies	Sample	Refractive correction	Instrument	Testing conditions	Results (D)
Chat (2001)	56 subjects (age range: 4 to 8 years) 24 M (> – 0.50 D), 18 EMM (± 0.50 D), 14 HYP (> + 0.50 D)	Nil	Open-field infra-red Shin-Nippon SRW-5000	Complete darkness	TA of M < EMM, M < HYP, EMM ≈ HYP TA in sphero-cylinder format: M = 0.76/–0.20 x 106 EMM = 1.35/–0.18 x 172 HYP = 1.50/–0.11 x 15
Wolffsohn et al. (2003)	35 (age range: 6 to 12 years) 25 EOM (– 1.63 D to – 5.63 D), 10 EMM (– 0.25 D to + 0.50 D)	Soft contact lens	Modified open-field infra-red Shin-Nippon SRW-5000 auto-refractor	0.1 cpd DOG target under dim illumination (25 cd/m^2) for 5 min.	TA of EOM (0.82) ≈ EMM (0.93)

Table 4.1. Results of studies on tonic accommodation, and their association with refractive error and age. TA: Tonic accommodation; M: Myopes; EMM: Emmetropes; HYP: Hyperopes; LOM: Late-onset myopes; EOM: Early-onset myopes; EMM_M: Emmetropes who became myopic; EMM_EMM: Emmetropes who remained emmetropic; DOG: Difference of Gaussian target; cpd: Cycle per degree; #: Longitudinal study.

Chapter 5. Nearwork-induced transient myopia

Introduction

Nearwork-induced transient myopia (NITM) is a temporary increase in myopia immediately after a near task. The literature (Ong and Ciuffreda, 1995; Ciuffreda and Wallis, 1998; Ciuffreda and Lee, 2002) suggests an association between NITM and onset and development of myopia. The first objective measurement of NITM, using an infra-red auto-refractor, was made by Enrlich (1987), and investigations of factors affecting NITM such as disparity-vergence and cognitive demand, were carried out thereafter (Rosenfield et al., 1992b; Rosenfield and Ciuffreda, 1994). However, few studies have been done to evaluate NITM in different refractive groups and their findings were not conclusive (Table 5.1).

5.1. Adults

Fisher et al. (1987) were the first investigators to study the relationship between NITM and refractive error. No significant difference was found in NITM between young adult high myopes, low myopes, emmetropes and hyperopes. Their findings did not, therefore, support the notion that NITM is a causative factor for onset of myopia. However, Fisher et al. recorded NITM after measurement of tonic accommodation, by which time NITM would have dropped to an insignificant level, and this possibly explains why no difference in NITM was found between groups.

Later NITM experiments generated a different picture (Ciuffreda and Wallis, 1998; Ciuffreda and Lee, 2002). Myopes were found to be more prone to NITM after sustained nearwork. These authors compared NITM in young LOM, EOM and emmetropes by asking them to carry out a near task, which required moderate cognitive demand, for 10 minutes at 5.0 D. NITM was calculated by pre-task minus post-task distance refraction and was considered as significant if its mean and SD exceeded the pre-task baseline variability by 1 SD. The post-task refraction change was monitored for 120 seconds after task cessation. NITM obtained in the first 10 seconds post-task was significant in myopes but not in emmetropes, while NITM of LOM was greater than that of EOM. For the change of NITM over the 120-seconds post-task period, NITM in LOM decayed to the pre-task level slower than in EOM. Ciuffreda and Wallis (1998) concluded that LOM might have weaker sympathetic innervation making them more susceptible to the development of myopia due to environmental factors such as nearwork. They further proposed that repeated occurrence of NITM would cause cumulative transient increase in myopic retinal defocus over time, and the situation would be more serious if lag of accommodation also occurred during near fixation. Such defocus would cause progression of myopia, not withstanding that it might be within one's depth of focus and lack a blur directional signal.

Ciuffreda and Wallis (1998) did not carry out tests to determine if there were statistically significant differences in NITM between LOM and EOM. They simply looked at the actual values and the difference in NITM (0.02 D) between the 2 myopic groups was certainly not clinically significant. Accommodative response was measured during near fixation in their experiment, but they did not report the values or make any comparison between groups. Any lag of accommodation which occurred during near viewing was not taken into consideration. Further, they started to measure post-task refraction 2 seconds after task removal, and this might have affected the results as NITM decreases over time (Rosenfield et al., 1992b).

Ciuffreda later extended the experiment with Lee by using a much longer near fixation time (Ciuffreda and Lee, 2002). Instead of 10 minutes, subjects were asked to read at their normal working distance for 4 hours. Distance refraction was measured immediately at the end of each hour of near task and the post-task refraction change was monitored for 20 minutes after the 4-hour near task. Ciuffreda and Lee (2002) concurred with the findings of Ciuffreda and Wallis (1998) that myopes were more prone to NITM. Comparing the averaged NITM over the 4-hour task, EOM yielded the greatest amount of NITM, followed by LOM and then emmetropes. All groups had their NITM decayed to pre-task level within the first minute post-task, with LOM experiencing the slowest rate of decay. NITM values found by Ciuffreda and Lee (2002) were less than those found by Ciuffreda and Wallis (1998), and the difference might be due to the small sample size (each group comprising 4 subjects) used in the former study. Ciuffreda and Lee (2002) set the near task at the subject's habitual working distance, and this of course varied between individuals. This would make the inter-group comparison difficult, as there was no control of near accommodation demand. Conceivably, some subjects might put the reading materials at 5.0 D and others at 2.5 D. Further, they did not mention the refractive error correction of their subjects during the experiment. Lens effectivity should be taken into consideration to account for the different accommodative demand in myopes and emmetropes, and it is not clear if this was done.

Vera-Diaz et al. (2002) was the first research group to study NITM in emmetropes, PM and SM. They repeated the work of Ciuffreda and Wallis (1998) but eliminated the effect of convergence. Subjects were required to carry out a near task with moderate cognitive demand for 10 minutes at 4.0 D. All accommodative responses were measured monocularly with subjects wearing contact lenses during the experiment when necessary. Progressive myopes had a greater lag of accommodation for a 4.0 D near task, and also greater lead of accommodation at distance than emmetropes and SM. They also had significantly greater NITM than emmetropes and SM, both at 10 and 30 seconds post-task. The decay rate of NITM to pre-task baseline level was slower in PM as compared with SM and emmetropes. In order to compare the results with those of Ciuffreda and Wallis (1998), Vera-Diaz et al. (2002) reclassified their myopes by onset of myopia, and found no statistically significant difference in NITM between refractive groups at 10 and 30 seconds post-task. From the above findings, different classification of myopia, by onset age or the progression of myopia, led to different findings in NITM between groups. Vera-Diaz et al. (2002)

suggested that some EOM had their myopia progressing and some stabilising. LOM had the similar dichotomous characteristic in myopia progression. NITM is therefore a feature during the progression of myopia.

All previous NITM experiments on adults have measured accommodation in static mode and there was an average of 2 seconds gap between each measurement taken by pressing the button of the auto-refractor (Ciuffreda and Wallis, 1998; Ciuffreda and Lee, 2002, Vera-Diaz et al., 2002). Further, there would be a delay in making the measurement after task removal as time was needed to allow the subjects to put their head back to the chin-rest of the auto-refractor. NITM dissipates with time (Rosenfield et al., 1992b) and the picture of NITM decay over time is not clearly shown by static readings. For example, NITM typically dissipates in the 30 seconds after task removal. If a subject needs, say, 2 seconds to put his/ her head on the chin rest, only 14 readings could be taken in the remaining time. The experiment described in this thesis made continuous recording of accommodation with a frequency of 60 Hz (i.e. 60 readings could be recorded in one second). Subjects were asked to put their head on the chin rest and to keep their posture during the experiment, allowing 1800 readings to be obtained in 30 seconds. This will give more accurate and reliable results as compared with those taken in static mode. Further, there has been only one study (Ciuffreda et al., 1996) on adults investigating the effect of dose on NITM, for example, by examining 2 identical tasks with different amounts of accommodation demand tasks and it is worthwhile to determine whether higher accommodative demand would give higher NITM in adults using a more advanced method.

There is high prevalence of myopia in Chinese but no work has been done to measure NITM in this population to see whether this parameter would be higher than in Caucasians or not.

5.2. Children

The first NITM experiment in children was carried out by Ciuffreda and Thunyalukul (1999). Their results were in agreement with those found in adults, that myopes were more susceptible to NITM than emmetropes. Child myopes experienced a more sustained NITM than adult myopes, and their NITM did not decay back to pre-task level within 2-minute post-task measurement time. The authors suggested that this was due to lower blur sensitivity in myopes than emmetropes and different levels of sympathetic innervation in children and adults. They predicted that children with recent onset of myopia who had NITM together with an increased lag of accommodation at near would exhibit cumulative retinal defocus leading to axial elongation. However, Ciuffreda and Thunyalukul (1999) measured accommodative responses under binocular conditions and convergence-induced accommodation would have affected the NITM values obtained.

With the development of advanced technology, Wolffsohn and his colleagues (including the present author) measured the NITM in Chinese children using a modified Shin-Nippon SRW-5000 auto-refractor operated in continuous mode (Wolffsohn et al., 2003). Subjects were asked to fixate a near target at 2 different accommodative demands (2.5 D and 5.0 D) and accommodative responses during near and distance fixation were recorded throughout the experiment. Results were similar to those found by Ciuffreda and Thunyalukul (1999), that is, myopes experienced greater NITM than emmetropes and their NITM existed longer than 3-minute post-task period. Greater near accommodative demand did not give greater NITM in either myopes or emmetropes. The NITM induced in Chinese children (Wolffsohn et al., 2003) was much higher than that reported in

Caucasian children (Ciuffreda and Thunyalukul, 1999), and this may partly explain the higher prevalence of myopia in Chinese. Wolffsohn et al. (2003) suggested a longitudinal study of NITM in Chinese should be carried out to confirm whether NITM has a role in the development of myopia.

5.3. Summary

Findings of previous investigations are shown in Table 5.1.The great majority of studies reported that both adult and child myopes experience greater NITM than emmetropes, however it is not known if this predates or post-dates the development of myopia. An answer to this question requires a longitudinal study. All studies, except Wolffsohn et al. (2003), measured NITM by use of auto-refractors in a static mode, however continuous mode measurement offers advantages as previously outlined and will be used in the present study.

Study	Sample	Refractive correction	Instrument	Near task	NITM results (D)
Fisher et al. (1987)	48 subjects (age range: 21 to 35 years) 12 High M (> − 4.00 D), 12 Low M (> − 0.75 D but ≤ − 4.00 D), 12 EMM (± 0.75 D), 12 HYP (> + 0.75 D)	Trial lens	Hartinger coincidence optometer	Monocular, 6/6 letter for 10 min at near point	NITM = 0.20 (whole sample) High myopes ≈ low myopes ≈ EMM ≈ HYP
Ciuffreda and Wallis (1998)	44 subjects (age range: 21 to 30 years) 11 LOM (mean = − 1.54 D, > 15 years onset), 13 EOM (mean = − 5.23 D, < 15 years onset), 11 EMM (± 0.25 D), 9 HYP (> + 0.25 D)	Soft contact lens	Canon R-1 auto-refractor	Binocular, Simple calculation for 10 min at 5 D	NITM in 10 s post-task: LOM (0.36) > EOM (0.34) > EMM (0.09) > HYP (0.01) Time constant of NITM decay: LOM (63 s) > EOM (35 s)
Ciuffreda and Lee (2002)	16 subjects (age range: 17 to 31 years) 4 LOM (> − 0.25 D, > 15 years onset), 4 EOM (> − 0.25 D, < 15 years onset), 4 EMM (− 0.25 D to + 0.75 D), 4 HYP (> + 0.75 D)	Unknown	Canon R-1 auto-refractor	Binocular, Reading for 4 hr at habitual working distance	NITM in 10 s post-task: EOM (0.13) > LOM (0.12) > EMM (0.09) > HYP (− 0.44) Time required for complete NITM decay: LOM > EOM and EMM

Study	Sample	Refractive correction	Instrument	Near task	NITM results (D)
Vera-Diaz et al. (2002)	41 subjects (age range: 18 to 27 years) [13 PM (> – 0.50 D, progressed > – 0.50 D over past 2 years), 14 SM (> – 0.50 D, progressed < – 0.50 D)] or [14 LOM (> – 0.50 D, > 15 years onset), 13 EOM (> – 0.50 D, < 14 years onset)], 14 EMM (– 0.25 D to + 0.50 D)	Soft contact lens	Canon R-1 auto-refractor	Monocular, 6/ 9 Snellen target for 10 min at 4 D	NITM at 10 s post-task: PM (0.33) > SM (0.17) and EMM (0.16) LOM ≈ EOM ≈ EMM NITM at 30 s post-task: PM (0.25) > EMM (0.09) and SM (0.04) LOM ≈ EOM ≈ EMM Time constant of NITM decay: PM (> 120 s) > SM (42 s) PM (> 120 s) > EMM (35 s)
Ciuffreda and Thunyalukul (1999)	25 subjects (age range: 4.7 to 9.9 years) 10 myopes, 10 EMM, 5 astigmats	Unknown	Canon R-1 auto-refractor	Binocular, near task with high cognitive demand for 10 min at 5 D	Only myopes showed significant initial NITM (0.15) Sustained throughout 2 min post-task period

Study	Sample	Refractive correction	Instrument	Near task	NITM results (D)
Wolffsohn et al. (2003)	45 subjects (age range: 6 to 12 years) 25 myopes (– 1.63 D to – 5.63 D), 10 EMM (– 0.25 D to + 0.50 D)	Soft contact lens	Modified Shin-Nippon SRW 5000 auto-refractor	Monocular, 6/6 Snellen letter for 5 min at 2.5 D and 5 D	NITM after 5 D: 60 s post-task, Myopes (0.47) > EMM (0.19); 120 s post-task, Myopes (0.49) > EMM (0.20); 180 s post-task, Myopes (0.52) > EMM (0.10) NITM after 2.5 D: 60 s post-task, Myopes (0.39) > EMM (0.12) 120 s post-task, Myopes (0.44) > EMM (0.03) 180 s post-task, Myopes (0.37) > EMM (0.03) Time required for complete NITM decay: Myopes > EMM

Table 5.1. Results of nearwork-induced transient myopia studies as a function of refractive error. M: Myopes; LOM: Late-onset myopes; EOM: Early-onset myopes; EMM: Emmetropes; HYP: Hyperopes.

Chapter 6. Aims of study

The notion that accommodation plays a role in the development and progression of myopia is still unproven, despite extensive studies to clarify their relationship. Most previous studies were carried out on Caucasians and information about accommodation characteristics in Chinese, a population with high prevalence of myopia, is lacking. Based on the results of previous work, the aims of the present study are now presented.

1. To investigate the amplitude of accommodation, accommodative stimulus-response curve, tonic accommodation and NITM in United Kingdom non-Chinese adults, Hong Kong Chinese adults and Hong Kong Chinese children using the same protocol by the same examiner.

2. To compare these measures in myopic and emmetropic subjects.

3. To study the effect of race by comparing these measures between United Kingdom non-Chinese adults and Hong Kong Chinese adults.

4. To investigate the effect of age by comparing these measures between Hong Kong Chinese adults and children.

5. To determine any changes in these responses in Hong Kong Chinese children as myopia develops/ progresses over one year.

Chapter 7. Methods and Instrumentation

The experiment comprised 4 parts: measurement of (a) amplitude of accommodation, (b) accommodative responses for the study of accommodative stimulus-response curve, (c) tonic accommodation and (d) nearwork-induced transient myopia (NITM). Three groups of subjects were recruited, namely non-Chinese adults, Chinese adults and Chinese children. Their refractive errors were considered in terms of mean spherical equivalent (MSE).

There are other alternative methods to describe refractive errors, such as the dioptric power matrix (Long, 1976), coordinator vector h (Harris, 1991) and power vector (Fourier decomposition of the power profile) (Thibos et al., 1997). The dioptric power matrix is a 2 × 2 matrix with components related to sphere, cylinder and axis. The coordinator vector h is a neater calculation method than the dioptric power matrix. It is a 3 × 1 matrix, in which each spherocylinder is considered as a vector. The vectors are then be manipulated by standard linear algebra matrices to generate means and standard deviations for sphere, cylinder and axis. In power vector, each clinical presentation is broken down into 3 components: the spherical equivalent (M) and 2 Jackson crossed-cylinder vectors,

J_0 and J_{45}. Power vector presentation is useful for sphero-cylinder lens combination, comparison of different lenses and the statistical distribution of refractive errors. The cylindrical power of the subjects in the current study was not high as those who had their astigmatism more than – 1.50 DC were excluded. MSE was used in this study to allow easy comparison with the literature. Moreover, the alternative methods mentioned above are useful in calculating the average power, but cannot help in classifying subjects into different refractive error groups. A recent study (Farbrother et al., 2004) developed another way to classify refractive groups. The authors claimed dividing subjects according to their mean spherical equivalent is an inappropriate method as spherical power and cylinder axis are related to each other. They suggested that ametropes should be grouped by considering their least deviation from emmetropia.

In the current study, MSE within the range ± 0.50 D were considered as emmetropic, while myopic subjects had an MSE of more than – 0.50 D (at least – 0.75 D). All results are reported in terms of mean ± standard deviation (SD). Statistical packages used to analyse data were SPSS v 11.01, Graphpad Instat v 3.00 and SigmaPlot v 8.0.

7.1. Subjects involved

7.1.1. Adults

Forty non-Chinese adults (20 emmetropes and 20 myopes) and 40 Chinese adults (20 emmetropes and 20 myopes), aged between 18 and 35 years, were recruited for this study. Data collection for non-Chinese adults was carried out in the Optometry Clinic, Aston University, United Kingdom, and that for Chinese adults was in the Optometry Clinic, The Hong Kong Polytechnic University, Hong Kong.

Both non-Chinese and Chinese adult subjects were fully informed verbally and in writing (attached in Appendix II A.2.1. and A.2.2. respectively) of the details of the experiment and were asked to sign informed consent forms (attached in Appendix III A.3.1.) before any measures were taken. They were required to make one visit only.

7.1.2. Chinese children

Both children and their parents were fully informed of the details of the experiment and parents were asked to sign informed consent forms before any measures were taken. The written information provided is shown in Appendix III A.2.3. and the consent form is shown in Appendix III A.3.2. A one-year longitudinal study (from August 2002 to August 2003) was carried out and families were asked to come back at 4-month intervals for data collection. Forty Chinese subjects (20 emmetropes and 20 myopes) aged between 9 and 12 years were initially recruited. The work was carried out in the Optometry Clinic, The Hong Kong Polytechnic University, Hong Kong.

Each subject (for all three groups) had:

- good ocular health,
- no binocular vision abnormality,
- best corrected visual acuity of 0.00 LogMAR or better, and
- astigmatism and/or anisometropia (sphere and cylinder) of not more than 1.50 D.

7.2. Instrumentation

The accommodative responses were measured using a modified Shin-Nippon SRW-5000 auto-refractor (Shin-Nippon, Japan). The SRW-5000 has been shown to provide valid and reliable measurement in adult and child emmetropes and myopes (Chat and Edwards, 2001; Mallen et al., 2001), and the repeatability and reproducibility of measures taken with the SRW-5000 are comparable with those obtained using the Canon R-1 auto-refractor (Chat and Edwards, 2001). Wolffsohn et al. (2001) modified the Shin-Nippon SRW 5000 auto-refractor to measure accommodative response continuously (measuring so-called dynamic accommodation). They further enhanced the technique by incorporating a Badal system to measure the accommodative response for different accommodative demands without the confounds of changing image size or luminance (Wolffsohn et al., 2003a). In brief, the modification involved setting the measurement ring of the auto-refractor permanently on, and the dynamic accommodative response was measured by means of LabView programming and Vision software (National Instruments, USA). The Shin-Nippon video output was transferred to a National Instruments PCI-1408 image acquisition card in an AMD Athlon 1GHz PC (in the Hong Kong work) and a Pentium III 700 MHz PC (in the United

Kingdom work) via the BNC (Bayonet Neill Concelman) connector on the output panel of the auto-refractor. There was a link motor system to instantaneously (< 100 ms) change the accommodative demand of the target. Figure 7.2.1. illustrates the experimental set-up, with a Badal system placed in front of the subject. Figure 7.2.2. shows the modified auto-refractor and Figure 7.2.3. shows the positions of the 2 near demand tasks.

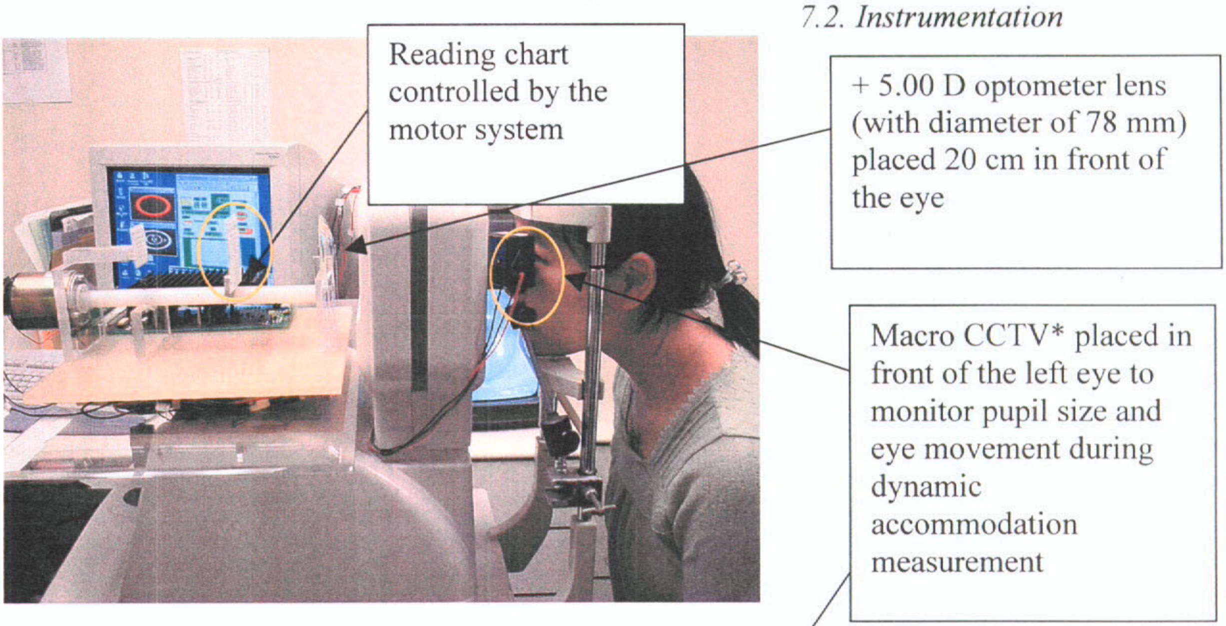

Figure 7.2.1. Sideview of the modified Shin-Nippon auto-refractor. * Closed circuit television.

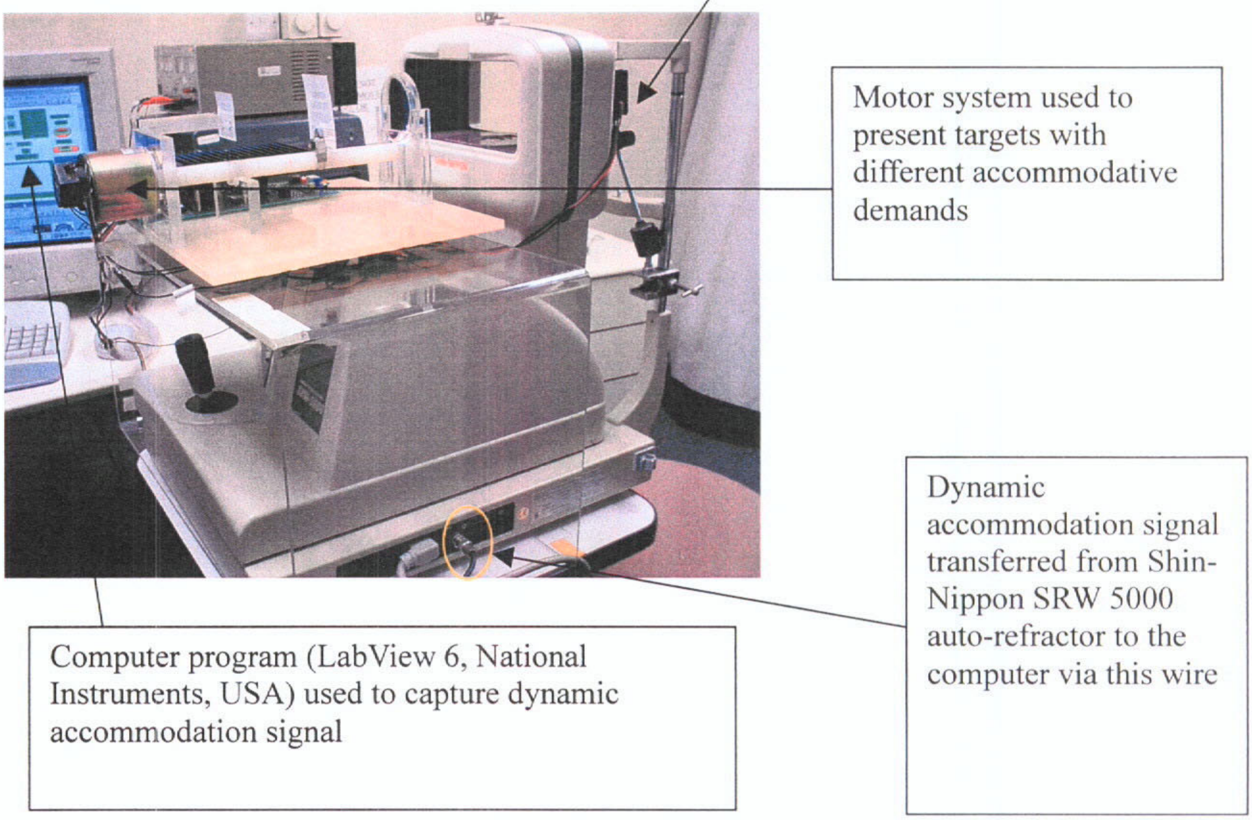

Figure 7.2.2. View of the modified Shin-Nippon auto-refractor.

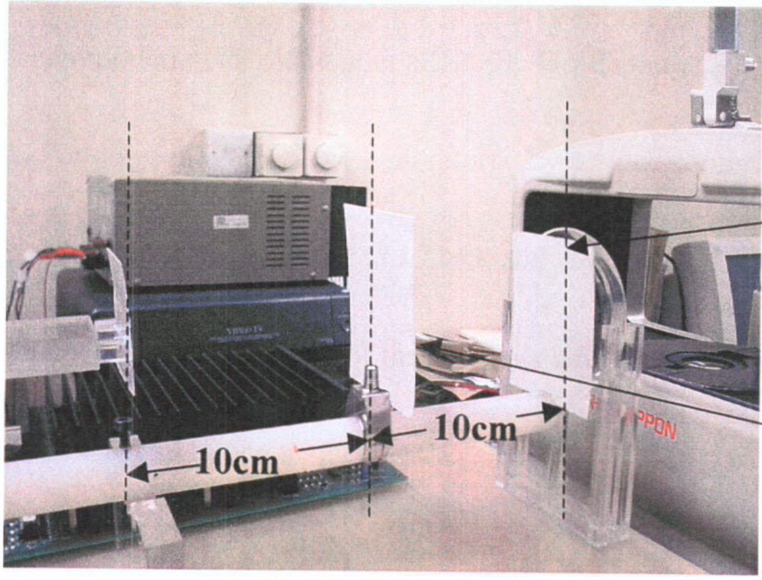

Figure 7.2.3. Positioning of 2.5 D and 5.0 D targets.

Compared with the Canon R-1 auto-refractor, the Shin-Nippon SRW 5000 auto-refractor provides a wider working range of at least 6.5 D (the range is less than 3.0 D in the Canon R-1), and allows greater eye movement with a smaller pupil size (the minimum pupil size required is 3.9 mm for the R-1, while the minimum pupil size required is just 2.9 mm for the SRW 5000) (Winn et al., 1989; Mallen et al., 2001). The modified Shin-Nippon auto-refractor can measure refractive error to a resolution of 0.001 D, and pupil size to a resolution of 0.001 mm (Wolffsohn et al., 2001).

In the present study, therefore, an appropriately modified Shin-Nippon open-field auto-refractor SRW 5000 (Shin-Nippon, Japan) was used to measure accommodation (Wolffsohn et al., 2001; Wolffsohn et al., 2003a), while the pupil size and eye movement were monitored by a video capturing system. The video capturing system consisted of a black and white CCTV (closed circuit television), which was placed in front of the subject's left eye and was connected to a 14″ TV/ VCR combo via a video cable.

7.3. Procedures

The research met the tenets of the Declaration of Helsinki and was approved by the institutional human experimentation committee of The Hong Kong Polytechnic University, Hong Kong and Aston University, United Kingdom. After receiving informed consent from adult subjects or a parent of child subjects, subjective refraction and ocular health check were carried out to ensure the potential subject met the recruitment criteria.

7.3.1. Measurement of visual acuity and refractive error

Visual acuity was measured by use of a LogMAR chart placed 6 m from the subject. The measurement ceased when the subject had read the entire 0.00 line.

Subjective refraction with binocular balancing, using the maximum plus for maximum acuity criterion, was done followed the auto-refraction taken by Shin-Nippon SRW-5000 auto-refractor (in static mode). Ultrasound biomicroscopy was not performed as it is an invasive method and involved instillation of local anaesthetic. Parents of the subjects might be discouraged to bring their children back due to safety reason.

7.3.2. Measurement of amplitude of accommodation

With the subject's distance refractive error carefully corrected in both eyes by full aperture trial lenses, amplitude of accommodation was measured using the push-up method. An RAF near point rule (Clement Clarke Ltd., England) was presented to the subject, the left eye being occluded. The subject was asked to fixate letters of N5 size and to report when the letters became blurred while the examiner pushed the target box closer. A reading lamp was used to make sure the measurement was done under photopic condition and the luminance was recorded as 68.52 ± 3.52 cd/m^2, measured by a photometer (Minolta LS-110, Japan). When the subject first reported blur, he or she was asked to blink and to make an effort to keep the target clear. A sustained blur for more than 5 seconds was considered as the "blur point". Two readings were taken and then averaged. The procedure was then repeated with the right eye occluded.

Subjects with myopia more than or equal to – 0.50 D were corrected by disposable soft contact lenses (One-day Acuvue, Johnson and Johnson) during the measurement of accommodative responses for the study of accommodative stimulus-response curve, tonic accommodation and nearwork-induced transient myopia. Unwanted effects from using spectacle lens/ trial lens (Gwiazda et al., 1993; Gwiazda et al., 1995; Abbott et al., 1998) were thus avoided and subjects were rendered functionally emmetropic.

Before the insertion of contact lenses, careful inspection of corneal health and measurement of corneal curvatures were carried out by examiner BY using a slit lamp/ biomicroscope Topcon SL-2E (Tokyo Optical Ltd., Japan) and a Canon RK-5 auto-keratometer (Canon Inc., Japan) respectively. Corneal health was considered as satisfactory if neovascularisation was less than 0.5 mm and there was no evidence of scar, infiltrate or oedema. Keratometry readings were used to inform the choice of base curve in the first contact lens selected. Assessment of the contact lens fitting was carried out after the subject had worn the lenses for at least 5 minutes. Re-insertion or replacement of the lens was carried out if the subject experienced any discomfort. One to two drops of artificial tears were instilled between sessions in order to avoid dryness of the eye which might affect the results.

7.3.3. Measurement of accommodative responses for the study of the accommodative stimulus-response curve

With the subject sitting comfortably in front of the Shin-Nippon SRW 5000 auto-refractor, the joystick of the auto-refractor was moved horizontally until a complete reticule circle was seen inside the pupil boundary of the right eye on the monitor. The circle ("necklace" of corneal reflections) was placed in sharp focus by adjusting the joystick forward and backward until a sharp reflection formed. The subject was asked to fixate a target positioned 6 m in front of the instrument and to keep the target as clear as possible during the measurement. The whole procedure was done under photopic conditions and the average luminance was 53.08 ± 1.11 cd/m^2. The measurement of accommodative response was made under monocular conditions with the left eye occluded, this facilitated the isolation of the accommodative response by opening the vergence loop. Accommodative responses were obtained by taking 10 consecutive readings manually while the subject maintained their focus on the target. The target was a row of letters equivalent to 0.00 LogMAR size and each letter subtended five minutes of arc. This accommodative response measurement procedures were repeated with a further 6 target cards, each with one row of letters to provide 0.00 LogMAR target size for distances of 2 m, 1 m, 1/2 m, 1/3 m, 1/4 m and 1/5 m – the sizes of the letters on each card varied according to the measuring distance to maintain the same angular subtense. The method of DDS was used in the current study, as it reflects the daily situation most by simulating what subjects actually face in normal daily life. Further, unlike PLS and NLS, as the addition of lens for providing different accommodative demands is not required in DDS, unwanted lens effects could be avoided. However, NLS has its advantage that it may be more sensitive to pick up difference in accommodative response between refractive groups. The auto-refractor generated an averaged reading (the "representative value") from the 10 measures taken from each distance and the MSE calculated from the representative value was used for analysis.

7.3.4. Continuous measurement of accommodation

A Badal system with a + 5.00 D lens (with diameter of 78 mm) was placed 20 cm from the target and another near acuity card was mounted on the plotter along the measurement axis of the auto-refractor. The purpose of using a Badal system is to keep a constant target size and luminance regardless of the accommodative demand. With the subject sitting comfortably in front of the instrument, the right eye was aligned with the target (0.00 LogMAR size) while the left eye's image of the target was obscured by a black and white CCTV placed in front of it. Convergence-induced accommodation will be eliminated under monocular conditions, providing a solely blur driven result. According to Hering's law of equal innervation (Millodot, 1993), the corresponding muscles of the two eyes are always equally innervated, so that one eye is never moved independently of the other. The online image of the left eye shown on the TV screen (Sharp, Japan) informed the examiner whether the subject maintained steady fixation. This was particularly useful when dealing with child subjects. It also provided information about unsuccessful measurement was due to small pupil size.

Dynamic accommodation was then measured, using the modified Shin-Nippon auto-refractor as already described, with a frequency of 60 Hz. That means the program received sixty readings from the auto-refractor each second. All the readings were saved in a computer file for future analysis.

Setting the zero reference point

Firstly, the subject was asked to fixate a 0.00 LogMAR letter through the Badal system. The accommodative response at optical infinity (target placed at anterior principal focus of the optometer lens) was then measured by taking 10 consecutive measures manually with the vertex distance (VD) of the SRW-5000 (in static mode) set as 12 mm. Since the auto-refractor reported refractive error measured at spectacle plane (spectacle lens power F_{sp}), each of the 10 static readings was converted to MSE and then to ocular power F_{oc} by applying the following equation.

$$F_{oc} = F_{sp} / 1- (0.012) (F_{sp})$$ -- **Equation A**

An example of the calculation of ocular accommodation for an emmetrope is shown below:

Spectacle refraction F_{sp} for target at optical infinity

= – 0.25/ – 0.25 X 180 (refractive error format)

= – 0.37 D (MSE format)

Therefore, spectacle accommodation = 0.37 D

↓

Ocular power F_{oc} (VD = 0 mm)

= – 0.37/ 1 – (0.012) (– 0.37) = – 0.37 D

Therefore, ocular accommodation = 0.37 D

The accommodative response was the mean of 10 ocular accommodation values. Before making any dynamic accommodation measurement, this mean ocular accommodation value was set as the "baseline (zero) reference point". From the above example, 0.37 D was set as the zero reference of that subject. This zero reference was for the calculation of the accommodative response resulting from different accommodative demands measured at dynamic mode. For example, if the accommodative response of the above subject is 4.37 D for a 5.0 D stimulus demand, by taking the zero reference as 0.37 D, the actual response arising from the near accommodative demand was 4.37 D minus the pre-existing accommodation of 0.37 D, or 4.00 D. In order to facilitate the measurement of dynamic accommodation, a reduced luminance (27.80 ± 0.25 cd/m^2) was used to minimise the effect of depth of focus and to ensure the pupil size was larger than 2.9 mm, the minimum pupil size for measurement (Mallen et al., 2001).

7.3.4.1. Measurement of tonic accommodation

The procedures used to measure the tonic accommodation and NITM were those used previously by Wolffsohn et al. (2003a).

Before measuring tonic accommodation, the subject was adapted to a reduced luminance (18.52 ± 0.26 cd/m^2) for 1 minute, while retaining fixation at optical infinity. Under a reduced luminance, the pupil would become larger so as to minimise the effect of depth of focus. Tonic accommodation was then measured by asking the subject to look at the centre of a 0.1 c/deg Difference-of-Gaussian (DOG) target (i.e. the light band of the target) presented at optical infinity for 5 minutes under the same luminance. Tonic accommodation was recorded as the average accommodation measured over the period between the first and sixth minutes.

7.3.4.2. Measurement of NITM

Subjects were asked to view letter targets (0.00 LogMAR) at different accommodative demands for the calculation of NITM. The following 4 tasks were carried out in random order, under a mean luminance of 27.80 ± 0.25 cd/m^2 in order to investigate the dose and stimulus effect on NITM.

Task A.

A near task for 5 minutes at 5.0 D followed by a distance task for 3 minutes.

Task B.

A near task for 5 minutes at 2.5 D followed by a distance task for 3 minutes.

Task C.

A distance task for 5 minutes followed by a near task at 5.0 D for 3 minutes.

Task D.

A distance task for 5 minutes followed by a near task at 2.5 D for 3 minutes.

The presentation of different target was made by the motor system, comprising a solenoid stepper motor which controlled the X-Y plotter instantaneously, presenting different targets in less than 100 ms. Subjects were asked to keep the letter targets as clear as possible during the experiment. A five-minute break (at least 5 minutes) was given between tasks to minimise fatigue and to allow the transient myopia to decay fully (Wolffsohn et al., 2003b).

7.4. Analysis of data

7.4.1. Amplitude of accommodation

The readings obtained from the right and left eyes were averaged. Since subjects wore trial lenses throughout this measurement, the averaged result was converted to ocular accommodation from spectacle accommodation using the following equation.

A = K − L --Equation B

where:

A = Amplitude of ocular accommodation

K = Ocular refraction

L = Vergence of light entering the eye

7.4.2. Accommodative stimulus-response curve

Ten static accommodative measures were taken for each distance (6 m, 2 m, 1 m, 1/2 m, 1/3 m, 1/4 m and 1/5 m) and the MSE for each distance, calculated by taking the representative value of these 10 measures as generated by the Shin-Nippon auto-refractor, was used for analysis. Since the vertex distance of the auto-refractor was set as 12 mm, ocular accommodation was calculated by transferring vertex distance from 12 mm to 0 mm using equation A (shown in 7.3.4.). Accommodative error at each accommodative demand was calculated by subtracting the accommodative demand from the accommodative response. For example, if the accommodative demand and response are 5.0 D and 4.3 D respectively, the accommodative error is equals to a 0.7 D lag. A positive value indicated a lag of accommodation and negative value indicates a lead of accommodation.

After an accommodation stimulus-response curve was plotted for each subject, a third-order polynomial curve was derived from SigmaPlot (version 8) with an equation of $y = yo + ax + bx^2 + cx^3$. Figure 7.4.2.1. shows the accommodative stimulus-response curve from one subject (Subject A) as an example. The derivation of the above equation indicated the gradient for each data point, i.e. each accommodation stimulus (O'Donnell et al., 2003; Jiang and O'Donnell, 2004). The gradient of the curve was an average of all the individual values. Figure 7.4.2.2. illustrates the gradient of accommodative stimulus-response curve for each stimulus point derived from the subject's data in Figure 7.4.2.1.

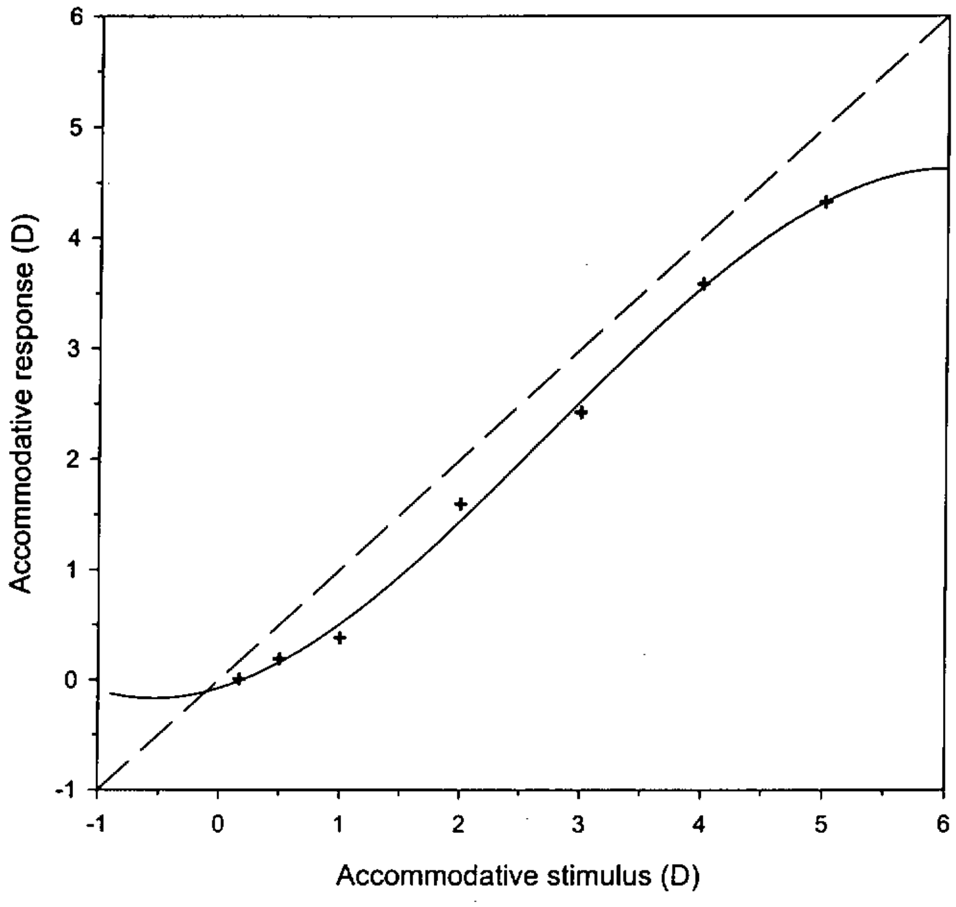

Figure 7.4.2.1. An example of accommodative stimulus-response curve. The polynomial equation is in the form of $y = -0.0753 + 0.3348x + 0.2801x^2 - 0.0342x^3$ for one subject (Subject A) as an example. The dotted line indicates the 1:1 line.

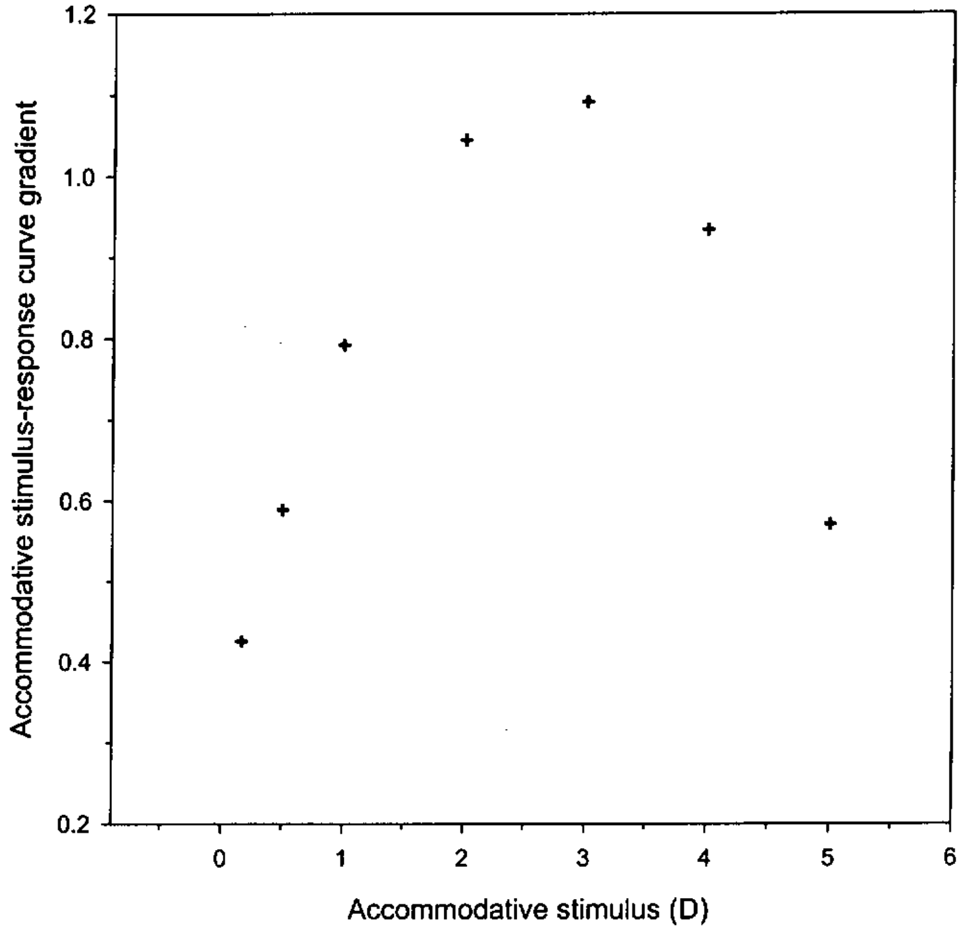

Figure 7.4.2.2. The gradient of accommodative stimulus-response curve derived from derivative of the equation in Figure 7.4.2.1.

7.4.3. Tonic accommodation

For a recording frequency of 60 Hz, a 5-minute (300 seconds) viewing time would generate 18,000 readings. These raw data collected from the computer program were input into a spreadsheet and used to generate the mean dynamic accommodation from every 10-second interval of the data (averaged from 600 readings). Accommodative response data that were not within 2.0 D of the task demand were treated as blink artefacts and removed (Gilmartin et al., 2002; Wolffsohn et al., 2003a; Wolffsohn et al., 2003b). Thirty mean dynamic accommodation results were generated (i.e. 18,000 readings/ 600 readings or from 300 seconds/ 10 seconds) and the mean of these represented the tonic accommodation.

7.4.4. NITM

The same computer program was used to generate the mean dynamic accommodation from every 10-seconds of the dynamic accommodation data. Blink artefacts were removed from the data using the principle previously described. A total of 48 readings were thus obtained during each 8-minute (480 seconds) fixation. The first second of data after change of stimulus was removed from analysis. It was because accommodative response usually takes less than 1 second to complete and the slow phase accommodative response is the principal component in NITM (Phillips et al., 1972; Hung and Ciuffreda, 1999; Wolffsohn et al., 2003a). For tasks A and B, the first 30 readings represented active accommodation, A1 ($A1_A$ for Task A and $A1_B$ for Task B), obtained from the first 5 minutes and the other 18 readings showed distance accommodation, D1 ($D1_A$ for Task A and $D1_B$ for Task B), after removal of accommodative demand targets. For tasks C and D, the first 30 readings represented baseline distance accommodation, D2 ($D2_C$ for Task C and $D2_D$ for Task D), during distant fixation for 5 minutes, and the remainder showed active accommodation, A2 ($A2_C$ for Task C and $A2_D$ for Task D), for near viewing. Both tasks C and D served the purpose of a control condition for tasks A and B. Figures 7.4.4.1 and 7.4.4.2 show examples of accommodative responses in Tasks A and C respectively. NITM during the first 10-seconds (1st to 10th second), the third 10-seconds (21st to 30th second), the first minute (1st to 60th second), the second minute (61st to 120th second) and the third minute (121st to 180th second) post-change were reported in the result section. The calculation of NITM was made from the mean distance accommodation D1 minus the mean distance accommodation D2.

Therefore, NITM during the first 10-seconds post-change in task A = Distance accommodation $D1_A$ at the first 10-seconds post-change – $D2_C$. NITM at the first 10-seconds post-change in task B = Distance accommodation $D1_B$ at the first 10-seconds post-change – $D2_D$.

For example,

Mean distance accommodation $D1_A$ at the first 10-seconds post-change = 0.5 D

Mean baseline distance accommodation $D2_C$ = 0.1 D

NITM at the first 10-seconds post-change in task A = (0.5 D – 0.1 D) = 0.4 D

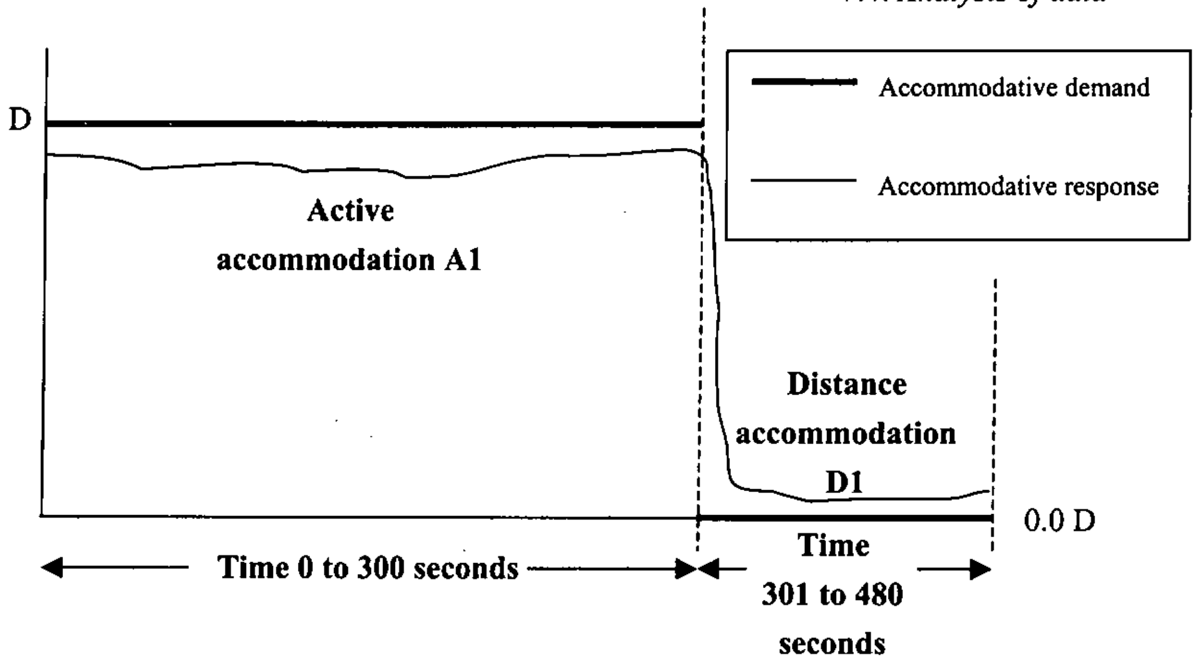

Figure 7.4.4.1. An example of accommodative responses in Task A (subject looking from 5.0 D to 0.0 D demand targets).

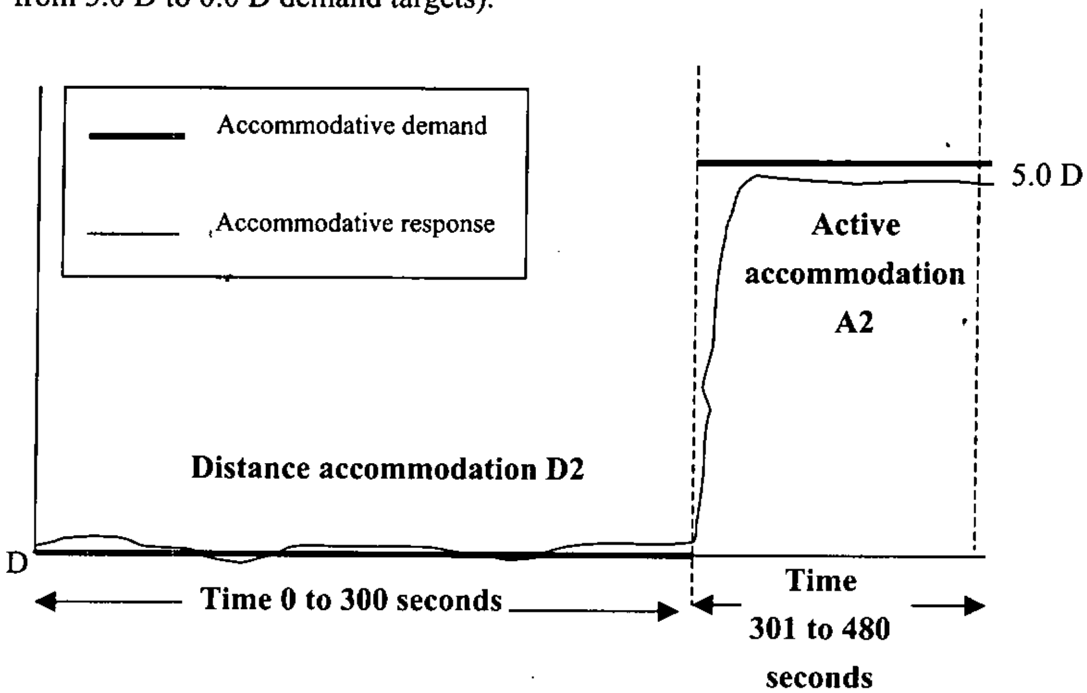

Figure 7.4.4.2. An example of accommodative responses in Task C (a control condition; subject looking from 0.0 D to 5.0 D demand targets).

7.5. Effect of contact lens

In the measurement of accommodative response for the study of accommodative stimulus-response curve, tonic accommodation and NITM, subjects with myopia more than or equal to MSE of – 0.50 D were required to wear disposable soft contact lenses during the experiment. Plano contact lenses of the type utilized were not available, so emmetropes did not wear contact lenses for the experimentation. Therefore the effect of a contact lens on the measurement of accommodation was investigated by repeating Task A with 8 Hong Kong Chinese young adult emmetropes (out of 20 subjects from Section 7.1.1.). They were required to wear disposable soft contact lenses with plano power (Focus Visitint, Ciba Vision) on their right eyes. Contact lenses from another brand were used because Johnson and Johnson does not manufacture soft disposable contact lenses with plano power. Results from both 5.0 D and 0.0 D demands with and without contact lenses were compared.

Part III. Results and Discussion

Preamble

The work described in this thesis generated a large volume of results. In order to make these more readable, and the significance of the findings more immediately clear, each set of results is followed by a discussion. The main findings for each study aim are finally summarised in Chapter 14.

The experimental results for non-Chinese adults, Chinese adults and Chinese children will be presented in the following chapters. Firstly, the subjects taking part in the work will be described in Chapter 8. Then results for amplitude of accommodation, accommodative response, tonic accommodation and NITM will be presented in chapters 9, 10, 11 and 12 respectively. The effects of contact lens wear on accommodative responses will be reported in Chapter 13.

Results are presented as mean and standard deviation (± SD), however the range is also given where appropriate. Refractive error is given as MSE and both ocular refraction and spectacle refraction will be reported. The ocular refraction is necessary for accurate determination of many of the parameters under consideration, while spectacle refraction is more familiar clinically and allows comparison with results from other studies which reported this parameter.

Chapter 8. Subjects

8.1. Adults

8.1.1. Non-Chinese adults

Forty-three non-Chinese adults were recruited, however 8 failed to give continuous traces of accommodative responses in at least one part of the NITM experiment due to poor fixation, and their data were excluded from the analysis in the whole study. Data from 35 non-Chinese adults (13 male) aged between 18 and 30 years (mean 21.17 ± 3.29 years) are presented. Seventeen subjects were emmetropic (ocular refraction, MSE – 0.11 ± 0.25 D, range + 0.38 D to – 0.50 D; spectacle refraction, MSE – 0.11 ± 0.25 D, range + 0.38 D to – 0.50 D), and 18 were myopic (ocular refraction, MSE – 3.64 ± 2.51 D, range – 0.62 D to – 9.03

D; spectacle refraction, MSE – 3.89 ± 2.81 D, range – 0.63 D to – 10.13 D).

There was no statistically significant difference in age between emmetropes (mean 21.00 ± 3.28 years) and myopes (mean 21.33 ± 3.40 years) (Unpaired t-test, $t = 0.30$, $df = 33$, $p > 0.05$). Most subjects were either Caucasian British or had come to the United Kingdom from India (Table 8.1.1.1.), and all were either staff or students of the Neurosciences Research Institute, School of Life and Health Sciences, Aston University, Birmingham, United Kingdom.

Country of family of origin	Number of subjects
India	19
United Kingdom	11
Greece	2
Bangladesh	1
Malaysia	1
Cyprus	1

Table 8.1.1.1. Country of family of origin of non-Chinese subjects.

Nineteen out of 35 United Kingdom subjects are ethnic Indians. They may confound the results on the comparison between non-Chinese and Chinese adults. Rambo and Sangal (1960) showed Indians had lower amplitude of accommodation than Europeans. The data from Indian adults were compared with those from other non-Chinese adults (Appendix VI). With the correction of age (as Indians were slightly younger than other United Kingdom adults), Indians had lower TA than other non-Chinese adults. The main theme of this study was to compare accommodative characteristics between non-Chinese and Chinese adults, in which Indians were also non-Chinese and therefore grouped together.

8.1.2. Chinese adults

Forty-three Chinese adults (26 male) aged between 19 and 32 years (mean 23.40 ± 2.85 years) were recruited. Twenty-one were emmetropic (ocular refraction, MSE 0.01 ± 0.28 D, range + 0.50 D to – 0.50 D; spectacle refraction, MSE 0.00 ± 0.28 D, range +0.50 D to – 0.50 D) and 22 were myopic (ocular refraction, MSE – 3.45 ± 2.36 D, range – 0.74 D to – 8.53 D; spectacle refraction, MSE – 3.68 ± 2.64 D, range – 0.75 D to – 9.50 D). There was no statistically significant difference in age between emmetropes (mean 22.76 ± 3.02 years) and myopes (mean 24.00 ± 2.62 years) (Unpaired t-test, $t = 1.44$, $df = 41$, $p > 0.05$).

8.1.3. Non-Chinese adults versus Chinese adults

Chinese adults (23.40 ± 2.85 years) were significantly older than non-Chinese adults (21.17 ± 3.29 years) (Two-way ANOVA, $F_{(1,74)} = 10.00$, $p < 0.01$). There was no significant difference in age between refractive groups ($F_{(1,74)} = 1.30$, $p > 0.05$) and no interaction effect between ethnic and refractive groups ($F_{(1,74)} = 0.40$, $p > 0.05$).

8.2. Children

8.2.1. Cross-sectional study

Thirty-one Chinese subjects (16 male) aged between 9 and 12 years (mean 10.68 ± 1.01 years) were recruited and baseline measures were taken in August 2002. At that time 8 of them were emmetropic (ocular refraction, MSE + 0.11 ± 0.41 D, range + 0.50 D to – 0.50 D, spectacle refraction, MSE + 0.11 ± 0.41 D, range + 0.50 D to – 0.50 D) and 23 were myopic (ocular refraction, MSE – 3.78 ± 1.65 D, range – 1.23 D to – 6.14 D; spectacle refraction, MSE – 3.99 ± 1.80 D, range – 1.25 D to – 6.63 D). Emmetropic children (10.00 ± 0.93 years) were about 1 year younger than myopic children (10.91 ± 0.95 years) (Unpaired t-test, $t = 2.36$, $df = 29$, $p < 0.05$). There were fewer emmetropic subjects involved, possibly because parents with myopic children were especially interested in participating in the study. All children were asked to return at 4-month intervals until August 2003, however results from the first visit only were used for comparison with Chinese adults.

8.2.2. Longitudinal study

It had been planned that Chinese children would make 4 data collection visits (i.e. at 4-month intervals over a 12-month period). Unfortunately, the number of subjects at the third visit dropped sharply due to the outbreak of Severe Acute Respiratory Syndrome (SARS) in Hong Kong during the period of data collection (i.e. March 2003). Some of the parents refused to bring their children back at that time. In order to maintain a large number of subjects in the longitudinal study, data collected at this visit was omitted. The time between the first and the second visits was 4 months, while that between the second and the final visits was 8 months. For easy understanding, the first visit is referred to as Visit A, second visit as Visit B and final visit as Visit C in the following discussion. Only data from subjects who attended all visits were analysed. The relationship between change of refractive error and the characteristics of accommodation in Chinese children could then be studied.

A total of 22 Chinese children (11 male) aged between 9 and 12 years (mean age 10.68 ± 1.01 years) completed the longitudinal study (Visits A, B and C). Six were emmetropes and 16 were myopes. Emmetropic children (10.17 ± 0.98 years) were about 1 year younger than myopic children (11.19 ± 0.83 years) (Unpaired t-test, $t = 2.44$, $df = 20$, $p < 0.05$). Details of their mean MSE are shown in Table 8.2.2.1.

Refractive groups	Type of refraction	Visit A	Visit B	Visit C
Emmetropes (n = 6)	Spectacle refraction	+ 0.17 ± 0.43 D + 0.50 D to – 0.50 D	– 0.19 ± 0.50 D + 0.25 D to – 1.00 D	– 0.29 ± 0.66 D + 0.50 D to – 1.25 D
	Ocular refraction	+ 0.17 ± 0.43 D + 0.50 D to – 0.50 D	– 0.18 ± 0.49 D + 0.25 D to – 0.99 D	– 0.29 ± 0.65 D + 0.50 D to – 1.23 D
Myopes (n = 16)	Spectacle refraction	– 4.09 ± 1.74 D – 1.25 D to – 6.13 D	– 4.36 ± 1.87 D – 1.25 D to – 6.50 D	– 4.64 ± 1.94 D – 1.63 D to – 7.00 D
	Ocular refraction	– 3.87 ± 1.60 D – 1.23 D to – 5.71 D	– 4.11 ± 1.72 D – 1.23 D to – 6.03 D	– 4.36 ± 1.76 D – 1.59 D to – 6.46 D

Table 8.2.2.1. The MSE (± SD) and range of refractive errors of emmetropes and myopes at each visit in the longitudinal study.

The overall progression of myopia was calculated by comparing the MSE in Visit A and Visit C. The mean increases in myopia for child emmetropes and myopes were – 0.46 ± 0.35 D and – 0.56 ± 0.42 D respectively. The increase in myopia from the current child emmetropes was more than the emmetropes found in Lam et al. (1999) (– 0.17 D), while that from the current child myopes was similar to values of myopes reported by Lam et al. (1999) (– 0.46 D) and by Edwards et al. (2002) (– 0.63 D). There was a statistically significant difference in MSE from Visit A to Visit C for both emmetropes (Repeated measures ANOVA, $F_{(2,10)} = 10.57$, $p < 0.05$) and myopes (Repeated measures ANOVA, $F_{(2,30)} = 20.63$, $p < 0.001$), both groups becoming more myopic with time. Post-hoc testing (Scheffe test) showed a significant increase in myopia in each visit for both groups. The increase in myopia in emmetropes from Visit A to Visit C (Figure 8.2.2.1) was similar to that in myopes (Unpaired t-test, $t = 0.50$, $df = 20$, $p > 0.05$).

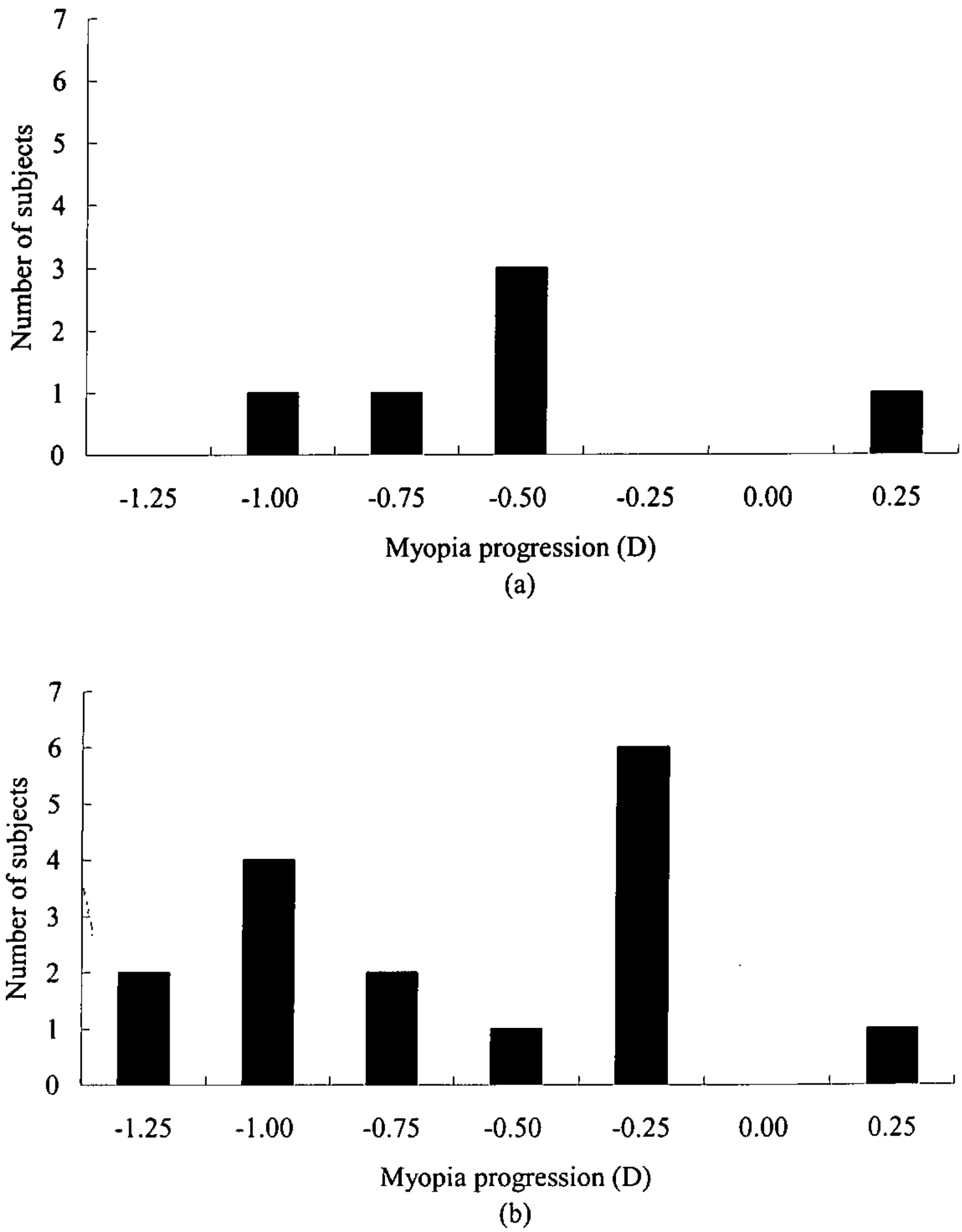

Figure 8.2.2.1. Distribution of myopia progression in (a) emmetropes (n = 6) and (b) myopes (n = 16). The mean (± SD) increases in myopia for emmetropes and myopes were – 0.46 ± 0.35 D and – 0.56 ± 0.42 D respectively.

Chapter 9. Amplitude of accommodation

The amplitudes of accommodation were found to be similar between the two eyes (Paired t-test, $p > 0.05$), so only amplitudes of accommodation of the right eyes are presented below.

For comparison with literature, myopes were further divided by the age of onset and by the progression of myopia. For the former classification, myopes were grouped as LOM if their myopia developed at or after the age of 15 years and as EOM if myopia developed before aged 15 years. For the latter classification, myopes were categorized as PM if their myopia progressed by – 0.50 D or more in the past 2 years and as SM if their myopia was stabilized or progressed less than – 0.50 D over this period. The criteria used in previous studies (Rosenfield and Gilmartin, 1987a; Ciuffreda and Ordonez, 1998; Jiang and Morse, 1999; Strang et al., 2000; Vera-Diaz et al., 2000; Ciuffreda and Lee, 2002; Vera-Diaz et al., 2002) have not always identified how myopes were classified if their myopia developed at aged 15 years or progressed by exactly 0.50 D.

As reported in Section 8.1.3., Chinese adults were older than non-Chinese adults and Chinese myopic children were older than Chinese emmetropic children. Literature (Kragha, 1989; Edwards et al., 1993; Atchison et al., 1994; Mordi and Ciuffreda, 1998; Chen et al., 2000) showed accommodative amplitude decreases with age. For the comparison in amplitude of accommodation between Chinese and non-Chinese adults and emmetropic and myopic children, analysis of covariance (ANCOVA) with age set as covariate were used.

9.1. Adults

9.1.1. Non-Chinese adults

9.1.1.a. Results

The mean amplitude of accommodation of non-Chinese adult emmetropes (n = 17) and myopes (n = 18) was 8.86 ± 1.62 D and 9.40 ± 2.30 D respectively. No statistically significant difference was found between the 2 refractive groups (Unpaired t-test, $t = 0.79$, $df = 33$, $p > 0.05$). Table 9.1.1.a.1. lists the number of LOM, EOM, emmetropes, PM, SM and their mean (± SD) refractive error and amplitude of ocular accommodation.

	LOM (n = 4)	**EOM (n = 14)**	**Emmetropes (n= 17)**	**PM (n = 10)**	**SM (n = 8)**
Spectacle refraction (D)	− 2.19 ± 1.52	− 4.38 ± 2.93	− 0.11 ± 0.25	− 4.65 ± 3.44	− 2.94 ± 1.44
Ocular refraction (D)	− 2.11 ± 1.45	− 4.08 ± 2.61	− 0.11 ± 0.25	− 4.30 ± 3.07	− 2.82 ± 1.32
Amplitude of accommodation (D)	9.53 ± 1.90	9.36 ± 2.46	8.86 ± 1.62	9.48 ± 1.72	9.31 ± 3.00

Table 9.1.1.a.1. The mean (± SD) spectacle and ocular refraction (MSE) and amplitude of accommodation of non-Chinese adult LOM, EOM, emmetropes, PM and SM.

There was no statistically significant difference either among LOM, EOM and emmetropes (Kruskal-Wallis test, $p > 0.05$) or among PM, SM and emmetropes (One-way ANOVA, $F_{(2,32)} = 0.32$, $p > 0.05$).

9.1.1.b. Discussion

Comparison between emmetropes and myopes

There was no difference in amplitude of accommodation between emmetropes and myopes. This demonstration of a similar amplitude of accommodation at similar age, regardless of refractive status, is supported by the findings of Gawron (1981). The equation developed by Hofstetter (1944) (See Section 2.1, Chapter 2) to estimate the minimum amplitude of accommodation clinically, is $15 - (0.25) \times (\text{age})$. The mean age of non-Chinese adults was 21 years and their amplitude of accommodation was calculated to be 9.75 D. This estimation is for spectacle accommodation and ocular accommodation will be less than that for both emmetropes and myopes. The non-Chinese adults in this study had accommodative amplitude similar to the estimated values (Emmetropes: 8.86 D; Myopes: 9.40 D).

Comparison between emmetropes and myopic sub-groups

Most of the previous studies compared accommodative amplitude among LOM, EOM and emmetropes. The results for LOM, EOM and emmetropes in the present study have not been compared with the literature as the number of subjects recruited in each sub-group was small. However, the accommodative amplitudes of LOM, EOM and emmetropes appear to be similar in the present study.

There appears to be no previous study comparing accommodative amplitude between emmetropes and myopes sub-divided according to the progression of myopia. The current study found no difference in accommodative amplitude among PM, SM and emmetropes. Fisher et al. (1987) compared emmetropes with high and low myopes and they did not find any significant difference.

9.1.2. Chinese adults

9.1.2.a. Results

The mean amplitude of accommodation for Chinese adult emmetropes (n = 21) and myopes (n = 22) was 8.49 ± 1.11 D and 8.63 ± 1.69 D respectively. The difference in amplitude between emmetropes and myopes was not statistically significant (Unpaired t-test with Welch correction, t = 0.31, df = 36, $p > 0.05$). The amplitudes of accommodation of LOM, EOM, emmetropes, PM and SM are listed in Table 9.1.2.a.1. There were no statistically significant differences either among LOM, EOM and emmetropes (One-way ANOVA, $F_{(2,40)} = 0.15$, $p > 0.05$) or among PM, SM and emmetropes (One-way ANOVA, $F_{(2, 40)} = 0.45$, $p > 0.05$).

	LOM (n = 9)	EOM (n = 13)	Emmetropes (n= 21)	PM (n = 5)	SM (n = 17)
Spectacle refraction (D)	– 1.72 ± 1.11	– 5.03 ± 2.56	0.00 ± 0.28	– 3.50 ± 3.59	– 3.73 ± 2.43
Ocular refraction (D)	– 1.68 ± 1.05	– 4.68 ± 2.24	0.01 ± 0.28	– 3.25 ± 3.23	– 3.51 ± 2.17
Amplitude of accommodation (D)	8.80 ± 1.27	8.51 ± 1.97	8.49 ± 1.11	8.11 ± 1.31	8.78 ± 1.80

Table 9.1.2.a.1. The mean (± SD) spectacle and ocular refraction (MSE) and amplitude of accommodation of Chinese adult LOM, EOM, emmetropes, PM and SM.

9.1.2.b. Discussion

Comparison between emmetropes and myopes

Results from Chinese adults again are supported by the findings of Gawron (1981) with no difference in accommodative amplitude between emmetropes and myopes. When compared with a study on Chinese subjects (Edwards et al., 1993), the amplitude of ocular accommodation found in this study were similar to their age-matched group. Edwards et al. (1993) did not report the accommodative amplitudes of different refractive groups and therefore comparison was not possible.

Comparison between emmetropes and myopic sub-groups

When referring to the results for myopic sub-groups, the current study also did not find any difference between LOM, EOM and emmetropes. This finding differed from some previously studies (Fledelius, 1981; Gawron, 1981; McBrien and Millodot, 1986a; Malingre and Wildsoet, 1995). McBrien and Millodot (1986a) found the greatest accommodative amplitude in LOM followed by EOM and emmetropes, while Fledelius (1981) and Malingre and Wildsoet (1995) showed a greater amplitude of accommodation in EOM compared to emmetropes. Different criteria used in the classification of myopia sub-groups might account for different results (Rambo and Sangal, 1960; Edwards et al., 1993; Ong and Ciuffreda, 1997). Fledelius (1981) defined their EOM as those having myopia greater than – 0.90 D while myopes in the current study were those having myopia greater than – 0.50 D. Malingre and Wildsoet (1995) did not state how they classified their myopes into LOM and EOM. In addition, the number of subjects in each myopic sub-group in the present study was small, decreasing the probability of identifying a statistical difference between refractive groups.

Factors affecting the amplitude of accommodation measurement could contribute to the difference in results. They include fatigue during measurement, willingness to obtain a clear image, understanding of and tolerance to blur, and the measuring skills of the examiners (Wold, 1967).

The results for PM, SM and emmetropes in the present study has not been compared with the literature as the number of subjects recruited in each sub-group was small. However, the accommodative amplitudes of PM, SM and emmetropes appear to be similar in the present study.

9.1.3. Non-Chinese adults versus Chinese adults

9.1.3.a. Results

The amplitude of accommodation of non-Chinese and Chinese adults were 9.14 ± 1.99 D and 8.56 ± 1.42 D respectively. There was no statistically significant difference between non-Chinese and Chinese adults (Two-way ANCOVA with age set as covariate, $F_{(1,73)} = 0.00$, $p > 0.05$) or between myopes and emmetropes ($F_{(1,73)} = 2.34$, $p > 0.05$), and there was no interaction between the groups ($F_{(1,73)} = 0.06$, $p > 0.05$).

9.1.3.b. Discussion

Previous studies found different amplitude of accommodation in different racial groups (Rambo and Sangal, 1960; Edwards et al., 1993). Rambo and Sangal (1960) found a lower accommodative amplitude in Indians than in Europeans. Edwards et al. (1993) reported a lower amplitude of accommodation in Chinese than that demonstrated in Caucasians by McBrien and Millodot (1986a). These studies did not carry out direct comparison between ethnic groups using the same protocol, instrumentation and examiners. Variation in examiners' instructions and measuring techniques could generate different results. The present study, using the same protocol and examiner for accommodative amplitude measurement, did not find any significant difference between Chinese and non-

Chinese adults. Current findings indicated that amplitude of accommodation was not a factor explaining the higher prevalence of myopia found in Chinese.

9.2. Chinese Children

9.2.1. Cross-sectional study

9.2.1.a. Results

The mean (± SD) amplitudes of accommodation for emmetropes and myopes in the first visit were 11.07 ± 1.22 D and 9.79 ± 0.94 D respectively. The emmetropes had significantly greater accommodative amplitudes than the myopes (One-way ANCOVA with age set as covariate, $F_{(1,28)} = 11.80$, $p < 0.05$).

9.2.1.b. Discussion

This was the first study reporting accommodative amplitude in different refractive groups in Chinese children. Edwards et al. (1993) investigated the amplitude of accommodation in Chinese. Their subjects were aged from 11 to 65 years. They reported the ocular accommodative amplitude of their youngest age group (7 subjects with mean age of 12.86 years) being 11.17 D. From the corresponding spectacle accommodative amplitude of 14.54 D, the mean spectacle refraction was derived to be – 3.25 D. The Chinese myopic children in this study were slightly younger (10.91 years) than their youngest group and had a lower amplitude of accommodation. Edwards et al. (1993) added an additional – 4.00 D or – 6.00 D lens if the subject's near point was closer than 10 cm in order to reduce the errors from the non-linear nature of the dioptre scale. The additional lens power was then subtracted from the amplitude of accommodation recorded from the scale. The current experiment did not add any lens during measurement and this might account for the difference in amplitude of accommodation between the two studies. Maturity of an individual that varies across different studies could also affect the interpretation of clear and blur (Wold, 1967). Another factor contributing to the difference in result between the two studies could be different target sizes. The target used in the current study was N5 print and Edwards et al. (1993) used LogMAR 0.3 target (equivalent to N6.3 print). Using a larger target could delay the appreciation of blur from the subject which could, in turn, lead to an increase in the amplitude of accommodation measured (Rosenfield and Cohen, 1995).

9.2.2. Longitudinal study

9.2.2.a. Results

Emmetropes had similar accommodative amplitudes to myopes throughout the study (Figure 9.2.2.a.1.) (Two-way repeated measures ANCOVA with age set as covariate, $F_{(1,19)} = 4.17$, $p > 0.05$). The amplitude of accommodation was similar during all visits ($F_{(2,38)} = 1.58$, $p > 0.05$). The interaction between refractive groups and visits failed to reach the significance ($F_{(2,38)} = 0.93$, $p > 0.05$).

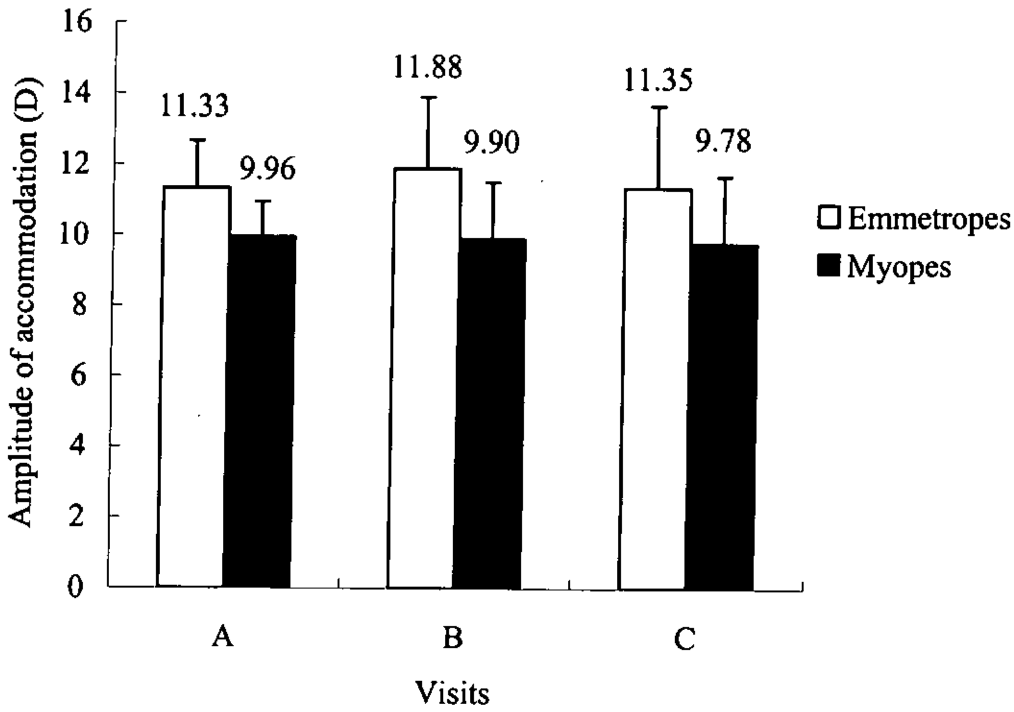

Figure 9.2.2.a.1.The mean amplitudes of accommodation of Chinese children in Visits A, B and C. The error bar represents one standard deviation.

In the current study, half of the emmetropes became myopic at the end of the longitudinal study and their accommodative amplitudes before and after the onset of myopia, together with the amplitudes from those who remained emmetropic were tabulated in Tables 9.2.2.a.1. No statistical test was done as there were only 3 subjects in each group.

	Visit A	**Visit C**
EMM_EMM (n = 3)	10.59 ± 0.76 D	10.48 ± 2.82 D
EMM_M (n = 3)	12.06 ± 1.49 D	12.23 ± 1.76 D

Table 9.2.2.a.1. The mean (± SD) amplitude of accommodation of child emmetropes who remained emmetropic (EMM_EMM) and became myopic (EMM_M) at the end of the longitudinal study.

9.2.2.b. Discussion

The change in amplitude of accommodation across visits was similar for emmetropes and myopes. No longitudinal study on the accommodative amplitude has been conducted previously. The similar accommodative amplitudes across visits could be due to the short study period of just one year. The re-grouping of emmetropes into those "becoming myopic" (EMM_M) and those "remaining emmetropic" (EMM_EMM) examined whether differences in amplitude of accommodation may be a precursor to myopic development. Three emmetropes became myopic (EMM_M) and 3 remained emmetropic (EMM_EMM) over 1 year study. Referring to Table 9.2.2.a.1., accommodative amplitude for both groups was similar from Visits A to C. EMM_M had a greater accommodative amplitude than EMM_EMM across the study. More emmetropes should be recruited for future investigations and the study period should also be extended.

9.3. Chinese adults versus children

9.3.1. Results

Comparing the amplitude of accommodation of Chinese adults and children in the cross-sectional study, two-way ANOVA (with refractive groups and age groups set as independent variables) demonstrated that the amplitude of accommodation of children (10.11 ± 1.15 D) was significantly higher than that of adults (8.56 ± 1.42 D) ($F_{(1, 70)} = 32.54$, $p < 0.001$). No statistically significant difference was found between refractive groups ($F_{(1,70)} = 3.09$, $p > 0.05$). There was an interaction effect between refractive groups and age groups ($F_{(1, 70)} = 4.69$, $p < 0.05$). Emmetropes had greater amplitude of accommodation than myopes in children, but the former group had similar amplitudes to the latter group in adults (Figure 9.3.1.1.). Difference in amplitude between children and adults was more prominent in emmetropes than in myopes (Figures 9.3.1.2.).

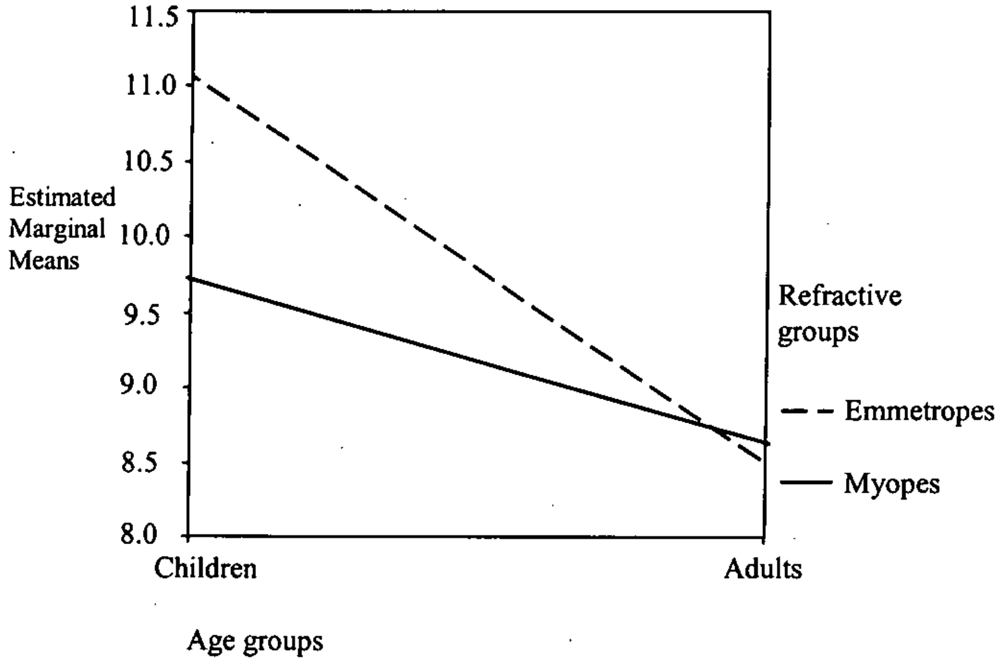

Figure 9.3.1.1. Interaction plot with refractive groups against age groups.

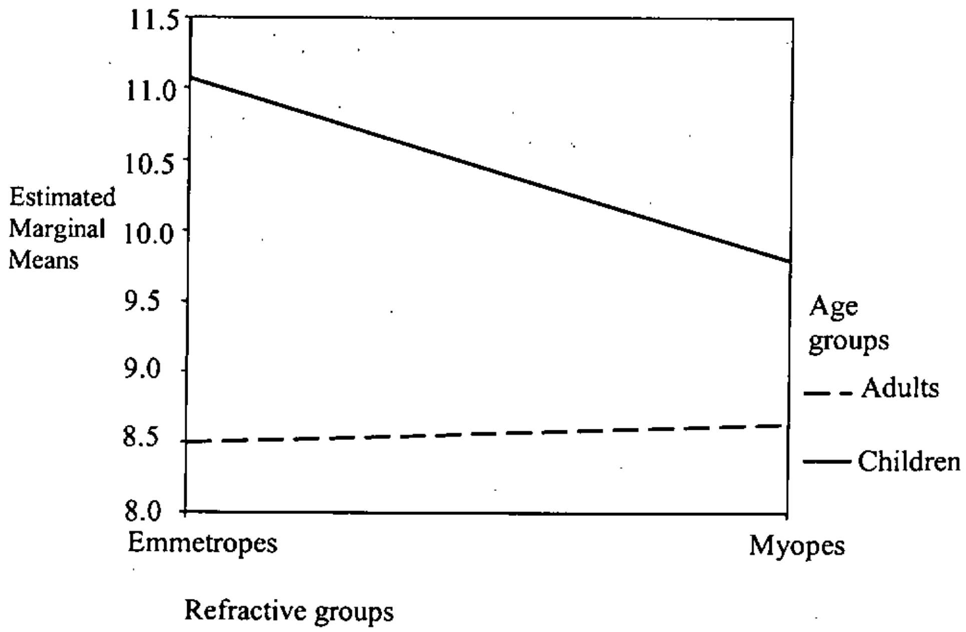

Figure 9.3.1.2. Interaction plot with age groups against refractive groups.

9.3.2. Discussion

The above findings were expected from previously reported literature (Kragha, 1989; Edwards et al., 1993; Atchison et al., 1994; Mordi and Ciuffreda, 1998; Chen et al., 2000) where accommodative amplitude decreases with age. Edwards et al. (1993) found the relationship between age and amplitude of ocular accommodation in Chinese can be expressed by $y = 14.84 - 0.27x$, where y is the amplitude and x is the age of the subject. The mean age of the Chinese adults and children in the current study were 23.40 years and 10.68 years respectively. By inserting their age into the equations developed by Hofstetter (1944) (See Section 2.1, Chapter 2) and Edwards et al. (1993), the minimum amplitude of accommodation in adults and children were calculated as 9.15 D and 12.33 D respectively by Hofstetter and 8.52 D and 11.96 D respectively by Edwards et al.. The difference between the 2 age groups found in this study (1.55 D) was smaller than that calculated from the equations by Hofstetter (3.18 D) and Edwards et al. (3.43 D). On the other hand, the mean difference of ocular MSE between children and adults were not significant for both refractive groups (Unpaired t-test with Welch correction, emmetropes (0.11 D), $t = 0.60$, $df = 9$, $p > 0.05$; myopes (0.33 D), $t = 0.54$, $df = 37$, $p > 0.05$). Effect of refractive errors was not a significant factor in explaining the difference in amplitude of accommodation between children and adults. In conclusion, age, rather than refractive errors contributed the difference in accommodative amplitude between children and adults.

9.4. Summary

1. Myopes had similar amplitude of accommodation with emmetropes in either non-Chinese or Chinese adults.

2. There were no significant differences in accommodative amplitude among LOM, EOM and emmetropes or among PM, SM and emmetropes in either non-Chinese or Chinese adults.

3. There was no significant difference in accommodative amplitude between non-Chinese and Chinese adults.

4. Child emmetropes had greater amplitude of accommodation than myopes.

5. Amplitude of accommodation remained similar throughout the longitudinal study for both child emmetropes and myopes.

6. Chinese children had greater accommodative amplitude than Chinese adults.

Chapter 10. The accommodative stimulus-response curve

Kalsi et al. (2001) demonstrated a decline in accommodative response gradient slowly from teenage up to 40 years and then more rapidly till the fifth decade. For the comparison in the accommodative stimulus-response curves between Chinese and non-Chinese adults and emmetropic and myopic children, analysis of covariance (ANCOVA) with age set as covariate were used.

10.1. Adults

10.1.1. Non-Chinese adults

10.1.1.a. Results

The mean gradients of the accommodative stimulus-response curves of emmetropes (n = 17) and myopes (n = 18) were 0.78 ± 0.16 and 0.77 ± 0.12 respectively. There was no statistically significant difference in gradients between the 2 refractive groups (Unpaired t-test, t = 0.18, df = 33, $p > 0.05$). The mean accommodative error was plotted against accommodative demand in Figure 10.1.1.a.1. The lag of accommodation tended to increase with increasing accommodative demand.

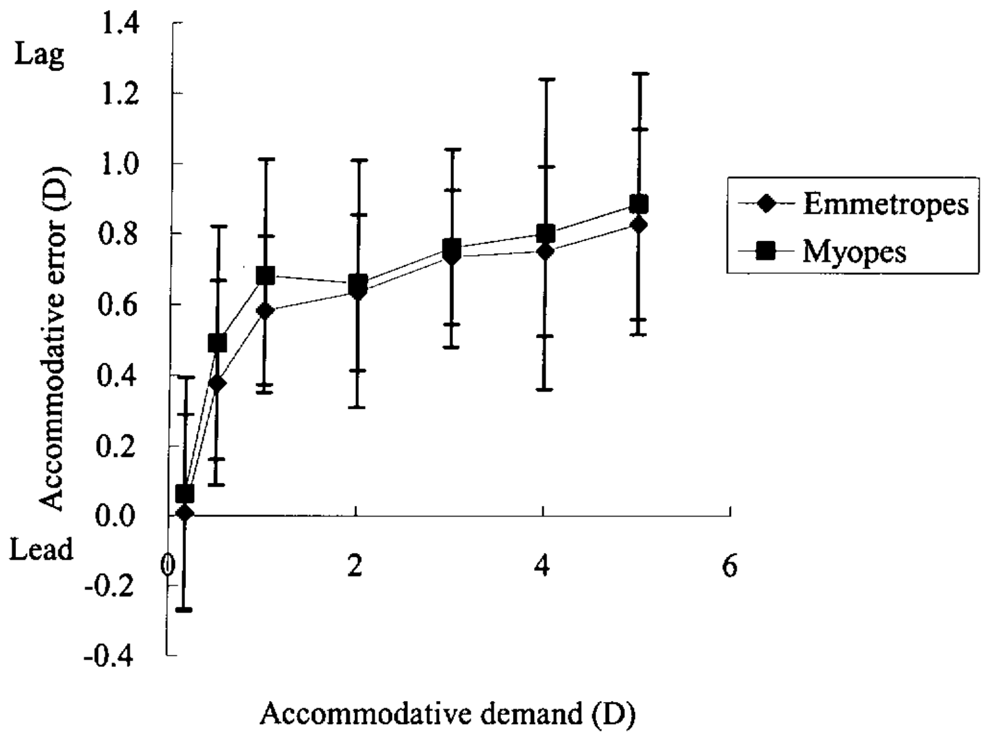

Figure 10.1.1.a.1. Accommodative error was plotted against accommodative demand in non-Chinese adults. The error bar indicates one standard deviation.

After dividing myopes into sub-groups based on criteria described in Chapter 9, accommodative response gradients of LOM, EOM, PM, SM and emmetropes are listed in Table 10.1.1.a.1.

LOM (n = 4)	**EOM (n = 14)**	**Emmetropes (n = 17)**	**PM (n = 10)**	**SM (n = 8)**
0.83 ± 0.07	0.76 ± 0.13	0.78 ± 0.16	0.74 ± 0.11	0.81 ± 0.13

Table 10.1.1.a.1. The mean (± SD) accommodative response gradient of non-Chinese adults. LOM: Late-onset; EOM: Early-onset myopes; PM: Progressing myopes; SM: Stable myopes.

There were no statistically significant differences in gradients among LOM, EOM and emmetropes (Kruskal-Wallis test, $p > 0.05$) or among PM, SM and emmetropes (One-way ANOVA, $F_{(2,32)} = 0.52$, $p > 0.05$).

10.1.1.b. Discussion

Advantages of the current method over the others

Instead of fitting the accommodative stimulus-response curve using linear regression function (McBrien and Millodot, 1986b; Gwiazda et al., 1993; Gwiazda et al., 1995a; Jiang, 1997; Abbott et al., 1998; Chen, 2002; Chen and O'Leary, 2002; Rosenfield et al., 2002; Nakatsuka et al., 2003; Seidemann and Schaeffel, 2003), a polynomial equation was used and its derivative represented the gradient of the curve at each stimulus (O'Donnell et al., 2003). The overall gradient for a subject was an average from all 7 stimuli. A typical stimulus-response curve of non-presbyope is S-shaped, with a central linear region (Charman, 1986). Linear regression analysis ignores the non-linearity of the curve, where gradient is not constant over the stimulus range. The current method of deriving the accommodative response gradient could be more accurate.

Comparison between emmetropes and myopes

As in some previous studies (Ramsdale, 1985; Chen, 2002), emmetropes had similar accommodative response gradient with myopes. Ramsdale (1985) did not find any significant association between accommodative response gradient and refractive error. Chen (2002) also could not find any significant difference in gradients between refractive groups. Both studies by Ramsdale (1985) and Chen (2002) used linear regression for the estimation of gradient, which assumed the accommodative stimulus-response curve to be linear, was not appropriate.

Accommodative lag was found to increase with accommodative demand (McBrien and Millodot, 1986b; Abbott et al., 1998; Nakatsuka et al., 2003; Seidemann and Schaeffel, 2003). From Figure 10.1.1.a.1, similar finding was revealed here. The lag of accommodation was not levelled off at 5.0 D demand but showed an increasing trend. This could be limited to the 5.0 D accommodative demand in the current study which was not great enough. The accommodative responses for those 7 accommodative stimuli were similar between emmetropes and myopes. The large standard deviation in accommodative error between emmetropes and myopes indicated large inter-subject variation (Ward and Charman, 1987; Kalsi et al., 2001; Seidemann and Schaeffel, 2003) which made the difference difficult to reach a significant level.

Comparison between emmetropes and myopic sub-groups

The results for LOM, EOM and emmetropes in the present study were not directly compared with the literature as the number of subjects was small. The difference was found to be insignificant among them.

The gradient was not statistically significant different among PM, SM and emmetropes. Previous studies also reported similar accommodative response gradient among different refractive groups using the DDS method (Ramsdale, 1985; Jiang, 1997; Abbott et al., 1998; Jiang and Morse, 1999; Chen, 2002; Nakatsuka et al., 2003). Abbott et al. (1998) found similar accommodative gradients between PM, SM and emmetropes in DDS method (the method adopted in current study), but a lower gradient in PM then SM and emmetropes in NLS method. Although NLS is a more sensitive method than DDS as reported by Gwiazda et al. (1993), it also has its drawbacks like reduction of accommodation with tilting of lens, monochromatic aberration and does not simulate a natural viewing condition. Jiang and Morse (1999) found no difference in gradients between refractive groups in DDS method with the use of a Badal system. Vera-Diaz et al. (2000) found a different result that PM had flatter gradient than SM and emmetropes. They did not report the method used in measuring accommodative response and so it is difficult to account for the different findings. It has been shown that different methods give different accommodative response gradients (Gwiazda et al., 1993; Abbott et al., 1998; Rosenfield et al., 2002), and this makes comparison with the present study difficult.

10.1.2. Chinese adults

10.1.2.a. Results

The mean accommodative response gradient for Chinese adult emmetropes (n = 21) and myopes (n = 22) were 0.84 ± 0.13 and 0.86 ± 0.11 respectively. There was no statistically significant difference in gradient between the 2 refractive groups (Unpaired t-test, t = 0.51, df = 41, p > 0.05). The mean accommodative error was plotted against accommodative demand in Figure 10.1.2.a.1. Emmetropes and myopes gave similar accommodative responses for all of the 7 accommodative stimuli. The lag of accommodation tended to increase with increasing accommodative demand.

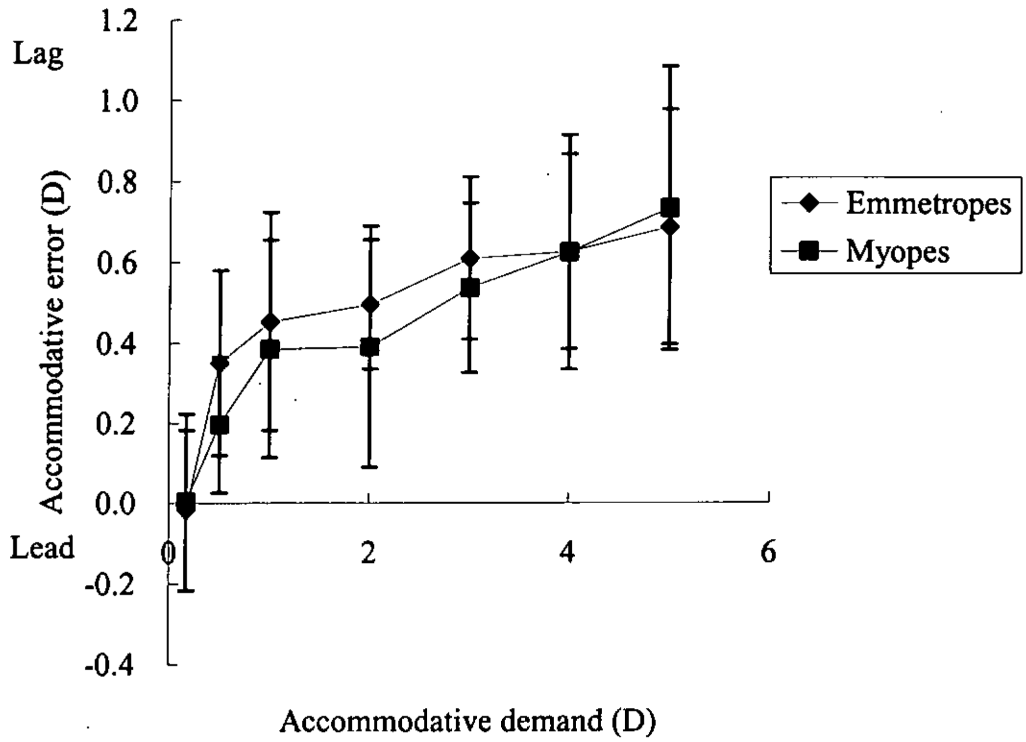

Figure 10.1.2.a.1. Accommodative error was plotted against accommodative demand in Chinese adults. The error bar indicates one standard deviation.

Accommodative response gradients of LOM, EOM, emmetropes, PM and SM are listed in Table 10.1.2.a.1.

LOM (n = 9)	**EOM (n = 13)**	**Emmetropes (n = 21)**	**PM (n = 5)**	**SM (n = 17)**
0.80 ± 0.07	0.90 ± 0.12	0.84 ± 0.13	0.75 ± 0.08	0.89 ± 0.11

Table 10.1.2.a.1. The mean (± SD) accommodative response gradient of Chinese adult late-onset and early-onset myopes, emmetropes, stable and progressing myopes.

There was no statistically significant difference in gradients among LOM, EOM and emmetropes (One-way ANOVA, $F_{(2,40)} = 1.99$, $p > 0.05$) or among PM, SM and emmetropes (One-way ANOVA, $F_{(2,40)} = 3.13$, $p > 0.05$).

10.1.2.b. Discussion

Comparison between emmetropes and myopes

Emmetropes had similar accommodative response gradient with myopes in the present study, which was similar to the results in previous studies (Ramsdale, 1985; Chen, 2002). From the plot showing accommodative error against accommodative demand (Figure 10.1.2.a.1.), the accommodative lag was greater for higher accommodative demands. The accommodative response for each accommodative stimulus was very close between emmetropes and myopes, and the findings are similar to other studies (Tokoro, 1988; Abbott et al., 1998; Chen, 2002; Hazel et al., 2003). Emmetropes and myopes in this study also shared large inter-subject variation in accommodative response (Ward and Charman, 1987; Kalsi et al., 2001; Seidemann and Schaeffel, 2003).

Comparison between emmetropes and myopic sub-groups

There were no statistically significant differences in gradients among LOM, EOM and emmetropes. Previous studies using the DDS method had similar findings as in the current study (Ramsdale, 1985; Jiang, 1997; Abbott et al., 1998; Jiang and Morse, 1999; Chen, 2002; Nakatsuka et al., 2003). Jiang (1997) and

Nakatsuka (2003) did not find any difference between LOM and emmetropes, or between EOM and emmetropes. Abbott et al. (1998) found similar gradients among LOM, EOM and emmetropes and the accommodative gradient was not associated with refractive error.

Some studies reported different gradients from different refractive groups. For example, McBrien and Millodot (1986b) observed the shallowest gradient from LOM (0.87), followed by EOM (0.88), emmetropes (0.92) and hyperopes (0.97). They did not report any statistical results. When referring back to their mean accommodative response gradient, the greatest difference compared with emmetropes was that from LOM. The difference was only 0.05. Jiang and White (1999) also found a shallower gradient from LOM than emmetropes. They corrected their ametropic subjects by either contact lens or trial lens, and did not consider that spectacle accommodation under-estimates the true ocular accommodative response of myope (due to lens effectivity effects) (Bennett and Rabetts, 1984). As the effectivity effect increases with the power of the spectacle lens, this would lead to a systematic error and a spurious relationship between accommodative response and refractive error.

McBrien and Millodot (1986b) reported a significant correlation between gradient and ocular refraction. Only emmetropes and myopes were involved in the present study, while McBrien and Millodot (1986b) recruited hyperopes as well and the higher correlation may be partly explained by a wider range of refractive error. Abbott et al. (1998) suggested that the correlation found by

McBrien and Millodot (1986b) was due to the differences in gradients between hyperopes and myopes, not for different degrees of myopia.

Ward and Charman (1985) observed a reduction in accommodative response gradient for pupil size under 2.9 mm, but not for pupil size over 2.9 mm. Variation of pupil size should not be a source of differences as auto-refractors used in the present and previous studies (McBrien and Millodot, 1986b; Bullimore et al., 1992; Jiang and White, 1999; Vera-Diaz et al., 2000) all required a minimum pupil diameter of 2.9 mm. Further, a recent study did not find any association between pupil size and accommodative lag (Seidemann and Schaeffel, 2003).

The difference in accommodative gradient between PM, SM and emmetropes in the present study was also insignificant. It was similar to those reported by the literature (Abbott et al., 1998; Jiang and Morse, 1999). Based on the findings from Abbott et al. (1998) on different myopic sub-groups, they concluded that accommodative insufficiency was related to the progression of myopia, rather than the age of onset. Although NLS is a more sensitive method than DDS (Gwiazda et al., 1993), it also has its drawbacks as reported in Section 10.1.1.b. Vera-Diaz et al. (2000) found opposite results with the current study. The authors reported a lower accommodative gradient in PM then SM and emmetropes. They, however, did not report their measurement method.

Other factors affecting accommodative responses include: instructions to subjects (Winn et al., 1991; Stark and Atchison, 1994; Chen and O'Leary, 2002), fixation errors (Seidemann and Schaeffel, 2003), mis-calibration of the instruments (Seidemann and Schaeffel, 2003), involvement of cognitive effort (Bullimore et al., 1992) and difference in psychological status (Gawron, 1981). In the present study, a standardised set of subject instructions were given by the same examiner which could avoid the variation of accommodative responses due to different instructions.

10.1.3. Non-Chinese adults versus Chinese adults

10.1.3.a. Results

The gradients of the accommodative stimulus-response curves for non-Chinese and Chinese adults are listed in Figure 10.1.3.a.1. Non-Chinese adults (0.78 ± 0.14) had accommodative response gradient similar to that of Chinese adults (0.85 ± 0.12). There was no significant difference in gradient between refractive groups (2-way ANCOVA with age set as covariate: $F_{(1, 73)} = 0.004$, $p > 0.05$) or between ethnic groups ($F_{(1, 73)} = 3.58$, $p > 0.05$) and there was no significant interaction between the refractive and ethnic groups ($F_{(1, 73)} = 0.16$, $p > 0.05$).

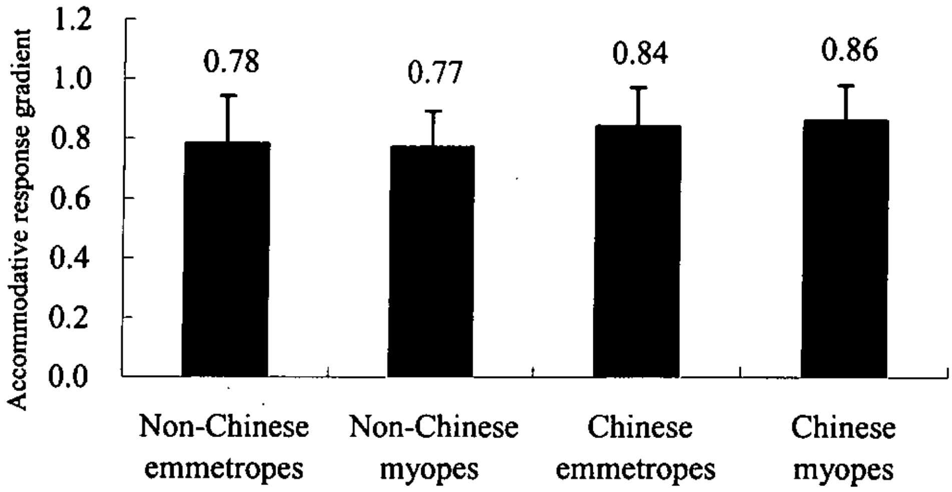

Figure 10.1.3.a.1. The mean accommodative response gradient of non-Chinese and Chinese adults. The error bar indicates one standard deviation.

10.1.3.b. Discussion

Although different populations could have different accommodative responses (Ramsdale and Charman, 1989; Seidemann and Schaeffel, 2003), the current study found a similar accommodative response gradients between non-Chinese and Chinese adults. This showed that accommodative response gradient was not a factor for the high prevalence of myopia in Chinese.

10.2. Chinese Children

10.2.1. Cross-sectional study

10.2.1.a. Results

The accommodative response gradient of emmetropes (n = 8) and myopes (n = 23) were 0.79 ± 0.16 and 0.68 ± 0.18 respectively. The difference between these 2 refractive groups was not significant (One-way ANCOVA with age set as covariate, $F_{(1,28)} = 2.93$, $p > 0.05$). When the accommodative error was plotted against accommodative demand (Figure 10.2.1.a.1), a greater accommodative lag was found for higher accommodative demands. Myopes had greater accommodative lag than emmetropes especially when accommodative demand increased.

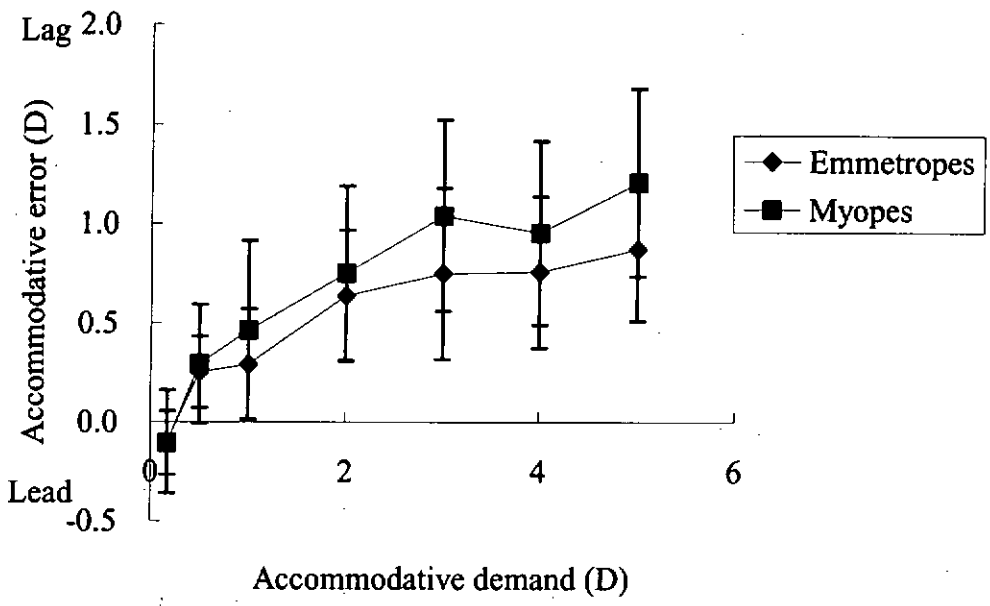

Figure 10.2.1.a.1. Accommodative error was plotted against accommodative demand in Chinese children in the cross-sectional study. The error bar represents one standard deviation.

10.2.1.b. Discussion

In the current study, emmetropes and myopes had similar accommodative response gradients. The accommodative response of myopes was lower than that of emmetrope in high accommodative demands (Figure 10.2.1.a.1). This indicated a greater accommodative lag in myopes and therefore a flatter accommodative response gradient was resulted. Myopes were found to have gradient 0.11 flatter than emmetropes here although the difference was not significant. Gwiazda et al. (1993 and 1995a) found flatter gradient in myopes than in emmetropes. Gwiazda et al. (1993) and Rosenfield and Abraham-Cohen (1999) suggested that child myopes have poorer blur sensitivity than emmetropes and this effect was more prominent when accommodative demands increased. This led to a flatter gradient in myopes. A later study (Schmid et al., 2002) on Chinese children found similar blur threshold in myopes and emmetropes, but myopes exhibited greater individual variation in blur detection. There was no correlation between blur threshold and refractive error progression or contrast sensitivity. The authors explained the greater variation shown in myopes might be due to different myopic sub-groups react differently to blur. Myopes in this study showed greater variation in accommodative lag than emmetropes and this might be caused by a greater variation in blur sensitivity as reported by Schmid et al. The sample size in the studies by Gwiazda et al. (1993) (16 myopes and 48 emmetropes) and Gwiazda et al. (1995a) (23 myopes and 40 emmetropes) was double that of the current study (16 myopes and 6 emmetropes). A small sample size would reduce the chance to obtain a significant difference between refractive groups. In addition, when referring to the data reported by Gwiazda et al. (1993), the accommodative responses were different between refractive groups for 3 D and 4 D stimuli only. The highest accommodative demand used here was 5 D only. Any further study should include a greater accommodative demand, or measured even to the amplitude of accommodation. Chen et al. (2003) recently reported no difference in accommodative response at 3.33 D between Chinese child PM, SM and emmetropes. As accommodative lag increases with accommodative demand, the stimulus used in Chen et al. (2003) was not big enough to demonstrate a significant difference in accommodative lag between refractive groups.

10.2.2. Longitudinal study

10.2.2.a. Results

The mean accommodative gradients at all visits are shown in Table 10.2.2.a.1. Two-way repeated measures ANCOVA with age set as covariate showed that emmetropes had similar accommodative response gradient with myopes throughout the study ($F_{(1,19)} = 3.35$, $p > 0.05$). There was no significant change in gradient between visits ($F_{(2, 38)} = 0.56$, $p > 0.05$). There was no statistically significant interaction between refractive group and visit ($F_{(2,38)} = 0.47$, $p > 0.05$).

	Visit A	**Visit B**	**Visit C**
Emmetropes (n = 6)	0.74 ± 0.12	0.86 ± 0.10	0.87 ± 0.06
Myopes (n = 16)	0.72 ± 0.19	0.75 ± 0.16	0.78 ± 0.16

Table 10.2.2.a.1. The mean (± SD) accommodative response gradient of child emmetropes and myopes at each visit.

In the current study, half of the emmetropes became myopic at the end of the longitudinal study. Their accommodative response gradients before and after onset of myopia, together with the gradients from those who remained emmetropic are listed in Tables 10.2.2.a.2. No statistical test was done as there were only 3 subjects in each group.

	Visit A	Visit C
EMM_EMM (n = 3)	0.68 ± 0.03	0.90 ± 0.08
EMM_M (n = 3)	0.81 ± 0.15	0.85 ± 0.01

Table 10.2.2.a.2. The mean (± SD) accommodative response gradient of child emmetropes who remained emmetropic (EMM_EMM) and those who became myopic (EMM_M) at the end of the longitudinal study.

10.2.2.b. Discussion

Child emmetropes had similar gradients as myopes during the longitudinal study. Polynomial equation was used to fit the accommodative stimulus-response curve. When linear regression was used as in previous studies (Gwiazda et al., 1993; Gwiazda et al., 1995a; Chen and O'Leary, 2002), a difference was found between emmetropes and myopes in the current study [c]. Child emmetropes had steeper gradients than myopes throughout the longitudinal study. Linear regression analysis has its drawback that the non-linearity of the curve is also treated as linear.

[c] The mean accommodative response gradients found by linear regression method was listed in Table 10.2.2.b.1.Two-way repeated measures ANCOVA showed emmetropes had significantly steeper gradient than myopes throughout the study ($F_{(1,19)} = 8.90$, $p < 0.05$). There was no significant change in gradient between visits (Two-way repeated measures ANCOVA, $F_{(2,38)} = 0.05$, $p > 0.05$). There was no statistically significant interaction between refractive group and visit ($F_{(2,38)} = 0.33$, $p > 0.05$).

	Visit A	Visit B	Visit C
Emmetropes (n = 6)	0.80 ± 0.08	0.88 ± 0.07	0.87 ± 0.06
Myopes (n = 16)	0.73 ± 0.12	0.76 ± 0.12	0.80 ± 0.09

Table 10.2.2.b.1. The mean (± SD) accommodative response gradient at each visit, found by linear regression method.

Both refractive groups did not demonstrate any significant change in gradient across visits. There has been no longitudinal study reporting the change in gradient with time. With the use of NLS method, Gwiazda et al. (1995a) found a reduction in the area under curve [d] when myopia increased in child myopes whereas the area was constant in emmetropes over the same time period. The increase in monochromatic aberration with increased accommodative stimulus produced by negative lens power in their study resulted in lag of accommodation (Collins, 2001; Hazel et al., 2003). The unwanted effect induced by negative lens used in NLS method, in addition to the trial lens correction apparently worn by some myopic children, would lead to a drop in accommodative response. Gwiazda et al. (1995a) also acknowledged a reduction of 5 to 6 % of accommodation due to 10 to 15 degrees forward tilting of the lenses used. Therefore, the drop in accommodative function with the increase in myopia might be due to unwanted effect induced by negative lens.

The re-grouping of emmetropes into "becoming myopic" (EMM_M) and "remaining emmetropic" (EMM_EMM) was for indicating the change in accommodative gradient before and after the onset of myopia. Three emmetropes became myopic (EMM_M) and 3 subjects remained emmetropic (EMM_EMM) over 1 year period. Referring to Table 10.2.2.a.2, gradient of EMM_M remained similar before and after onset of myopia, while that of EMM_EMM increased across study. Gwiazda et al. (1995a) observed, anecdotally, that one of their child

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[d] Area under curve = (Accommodative demand at the break point x accommodative response at the break point) / 2, where break point was the accommodative demand at the rightmost point of the linear portion of the accommodative stimulus-response curve (Gwiazda et al., 1995a).

emmetropes who became myopic had flatter gradient than the others at the end of the study.

10.3. Chinese adults versus children

10.3.1. Results

Comparing the accommodative response gradient of Chinese adults and children in the first visit, adults had accommodative response gradients closer to unity (0.85 ± 0.12) than children (0.71 ± 0.18) (Two-way ANOVA, $F_{(1,70)} = 9.58$, $p < 0.05$). There was no difference in gradients between refractive groups ($F_{(1,70)} = 1.33$, $p > 0.05$) and the interaction between refractive groups and age groups was not significant ($F_{(1,70)} = 2.78$, $p > 0.05$).

10.3.2. Discussion

Kalsi et al. (2001) demonstrated a decline in accommodative response gradient slowly from teenage up to 40 years and then more rapidly till the fifth decade. Chen and O'Leary (2002) studied the effect of age on gradient and accommodative lead and lag, but could not find any effect from their emmetropic subjects aged between 3 and 14 years. Similarly, Mordi and Ciuffreda (1998) could not find any significant correlation between age and gradient in their subjects aged between 21 and 50 years old. In contrast, the current findings showed that adults had steeper accommodative response gradients than children. The gradient therefore did not flatten with age, but rather steepened from the first to the second decade. There are previous studies with similar findings (Gwiazda et al., 1995a; Abbott et al., 1998). The gradients obtained in adults using the NLS method (Abbott et al., 1998) were steeper than those in children (Gwiazda et al., 1995a) and it has been suggested that the difference is due to children having greater difficulty accommodating through negative lenses (Abbott et al., 1998). In the present study, children were also poorer accommodators than adults in DDS method. Further, Nakatsuka et al. (2003) suggested accommodative lag found in myopic children can improve with age and this may explain why adults had steeper gradients than children.

10.4. Summary

1. Accommodative response gradient was independent of ocular refraction in both non-Chinese and Chinese adults.

2. There were no differences in gradient and accommodative response between adult emmetropes and myopes.

3. Non-Chinese and Chinese adults experienced similar gradients, suggesting that high prevalence of myopia in Chinese is not due to differences in accommodative responses.

4. Child myopes had similar gradient to emmetropes, suggesting that both groups had similar blur sensitivity.

5. Accommodative gradient remained unchanged throughout the longitudinal study. The proposal that flattening of accommodative response gradient is a characteristic of the development of myopia could not be substantiated.

6. Chinese children had flatter accommodative response gradient than adults.

Chapter 11. Tonic accommodation

Literature showed tonic accommodation decreases with age (Whitefoot and Charman, 1992; Mordi and Ciuffreda, 1998). For the comparison in the tonic accommodation between Chinese and non-Chinese adults and emmetropic and myopic children, analysis of covariance (ANCOVA) with age set as covariate were used.

11.1. Adults

11.1.1. Non-Chinese adults

11.1.1.a. Results

The mean values for tonic accommodation in emmetropes (n = 17) and myopes (n = 18) were 1.06 ± 0.53 D and 0.94 ± 0.53 D respectively. There was no statistically significant difference between the 2 refractive groups (Unpaired t-test, $t = 0.63$, $df = 33$, $p > 0.05$). Myopes were further classified according to the age of onset of myopia (late-onset myopes and early-onset myopes) or the progression of myopia (progressing myopes and stable myopes), using the criteria adopted in Chapter 9. The mean values for tonic accommodation in LOM, EOM, PM, SM and emmetropes are listed in Table 11.1.1.a.1. There was no statistically significant difference in tonic accommodation either among LOM, EOM and emmetropes (Kruskal-Wallis test, $p > 0.05$) or among PM, SM and emmetropes (One-way ANOVA, $F_{(2,32)} = 1.39$, $p > 0.05$).

LOM (n = 4)	EOM (n = 14)	Emmetropes (n = 17)	PM (n = 10)	SM (n = 8)
1.21 ± 0.81 D	0.87 ± 0.43 D	1.06 ± 0.53 D	0.78 ± 0.61 D	1.15 ± 0.34 D

Table 11.1.1.a.1. The mean (± SD) tonic accommodation of non-Chinese adults. LOM: Late-onset myopes; EOM: Early-onset myopes; PM: Progressing myopes; SM: Stable myopes.

11.1.1.b. Discussion

Advantages of the current method over the others

An infra-red optometer was used to measure tonic accommodation in the current study. Use of the laser optometer and Hartinger coincidence optometer (Ramsdale, 1985; Fisher et al., 1987; Hung and Ciuffreda, 1991) required subjective identification of the direction of speckle pattern and the position of luminous bars respectively. These involve cognitive effort and stimulate proximal accommodation leading to an increase in accommodative response (Post et al., 1984; Rosenfield et al., 1990; Rosenfield et al., 1992a). The infra-red optometer has the advantage over the other 2 types of providing stimulus-free condition and does not require subjective judgment of target position.

Tonic accommodation was continuously monitored here by a modified infra-red open-field Shin-Nippon SRW 5000 auto-refractor for 5 minutes and the machine was able to record accommodative response every 0.017 second. Around 18,000 readings were obtained and then averaged to give the final value of tonic accommodation. The method used here could provide a more reliable reading than just recording the tonic accommodation in a static mode. For example, Rosenfield and Gilmartin (1989) also used a modified infra-red open-field auto-refractor (Canon R-1) to measure accommodative response for 5 minutes, but they only took 10 measurements each minute. Their mean tonic accommodation was then obtained from the average of 50 readings.

Comparison between emmetropes and myopes

The results here supported the finding by Ramsdale (1985) and the Cardiff study by Maddock et al. (1981) with similar tonic accommodation between emmetropes and myopes. Other studies (Gawron, 1981; Tokoro, 1988; Adams and McBrien, 1993) showed a different trend compared with the present study. Adams and McBrien (1993) found a lower tonic accommodation in myopes than emmetropes. They had subjects with a wide age range so that aging effect could influence the results. Gawron (1981) and Tokoro (1988) showed higher tonic accommodation in myopes than emmetropes. Gawron (1981) did not specify their measuring condition. Tokoro (1988) presented a moving target to his subjects and this had an associated cognitive effort. The higher tonic accommodation found in myopes by Tokoro might be due to the presence of mental factors leading to relatively greater increase in tonic accommodation in myopes, as shown by Bullimore and Gilmartin (1987).

Comparison between emmetropes and myopic sub-groups

The results for LOM, EOM and emmetropes in the present study had not been compared with the literature as the number of subjects recruited in each sub-group was small. The difference in tonic accommodation among LOM, EOM and emmetropes was not significant here.

There was no difference in tonic accommodation among PM, SM and emmetropes in the present study and this did not agree with the findings by previous studies (Gawron, 1981; Tokoro, 1988; Jiang and Morse, 1999; Vera-Diaz et al., 2000). Jiang and Morse (1999) showed higher tonic accommodation in PM than SM and emmetropes. They proposed that an increased in tonic level would help to reduce accommodative lag at near, and hence influence the oculomotor system to stimulate changes in the characteristics of the eye. Later, Vera-Diaz (2000) found PM and emmetropes had higher tonic accommodation than SM. Jiang and Morse (1999) used different refractive corrections, either soft contact lens or trial lens for their subjects. It is not clear if lens effectivity was considered. Vera-Diaz (2000) did not specify their measuring condition.

11.1.2. Chinese adults

11.1.2.a. Results

The mean tonic accommodation for Chinese adult emmetropes (n = 21) and myopes (n = 22) were 1.07 ± 0.45 D and 0.96 ± 0.55 D respectively. The tonic accommodation was similar in the two groups (Unpaired t-test, $t = 0.78$, $df = 41$, $p > 0.05$). Myopes were further categorized into LOM, EOM, PM and SM. Their tonic accommodation with that from emmetropes are listed in Table 11.1.2.a.1. There was no statistically significant difference in tonic accommodation either among LOM, EOM and emmetropes (One-way ANOVA, $F_{(2,40)} = 0.30$, $p > 0.05$) or among PM, SM and emmetropes (One-way ANOVA, $F (2,40) = 0.39$, $p > 0.05$).

LOM (n = 9)	**EOM (n = 13)**	**Emmetropes (n = 21)**	**PM (n = 5)**	**SM (n = 17)**
0.95 ± 0.60 D	0.96 ± 0.54 D	1.08 ± 0.45 D	1.05 ± 0.36 D	0.93 ± 0.60 D

Table 11.1.2.a.1. The mean (± SD) tonic accommodation of Chinese adults. LOM: Late-onset myopes; EOM: Early-onset myopes; PM: Progressing myopes; SM: Stable myopes.

11.1.2.b. Discussion

Comparison between emmetropes and myopes

There has been no literature reporting tonic accommodation in Chinese before. Current finding agreed with those by Ramsdale (1985) and the Cardiff study by Maddock et al. (1981), but opposed those by other studies (Gawron, 1981; Tokoro, 1988; Adams and McBrien, 1993). The possible reasons for different findings have been explained in previous section (Section 11.1.1.b.).

Comparison between emmetropes and myopic sub-groups

McBrien and Millodot (1987) divided their myopes according to age of onset of myopia. Their LOM were found to have lower tonic accommodation (0.49 D) than emmetropes (0.89 D), but EOM had similar tonic accommodation (0.92 D) to emmetropes. They suggested LOM had lower parasympathetic innervation than emmetropes, leading to a reduction in tonic accommodation. However, the results reported here do not support their findings, even after the classification of myopes according to either age of onset of myopia or myopic progression.

The current findings among LOM, EOM and emmetropes were similar to most of the previous findings (Ramsdale, 1985; Fisher et al., 1987; Rosenfield and Gilmartin, 1988b; Rosenfield and Gilmartin, 1989; Morse and Smith, 1993; Woung et al., 1993; Strang et al., 1994; Jiang, 1997; Jiang and White, 1999; Strang et al., 2000). Other studies found late-onset myopes (McBrien and Millodot, 1987; Rosenfield and Gilmartin, 1987a; Jiang, 1995) had lower tonic accommodation than emmetropes.

Reasons for the discrepancy between current study and others (Gawron, 1981; McBrien and Millodot, 1987; Rosenfield and Gilmartin, 1987a; Tokoro, 1988; Hung and Ciuffreda, 1991; Adams and McBrien, 1993; Jiang, 1995; Jiang and Morse, 1999; Vera-Diaz et al., 2000) could be the use of a different mode of measurement (static or continuous), different refractive grouping criteria (Ong and Ciuffreda, 1997), different subject age ranges (Whitefoot and Charman, 1992; Mordi and Ciuffreda, 1998), variations in the amount of mental effort/ cognitive demand on accommodation in different refractive groups (Jaschinski-Kruza and Toenies, 1988; Winn et al., 1991), different viewing conditions (Ong and Ciuffreda, 1997), visual imagery under complete darkness (Westheimer, 1957; Malmstrom and Randle, 1976), surround propinquity (for example, higher tonic accommodation was found in a smaller-sized room than in a larger room) (Rosenfield and Ciuffreda, 1991), fatigue (leading to a reduction in tonic accommodation) (Hasebe et al., 2001), stress (leading to an increase in tonic accommodation) (Miller and LeBeau, 1982), subject's mood (Miller, 1978), and the reference plane (spectacle or ocular plane) that tonic accommodation refers to (Fisher et al., 1987).

Tonic accommodation has great inter-subject variation (Strang et al., 2000). Fisher et al. (1987) and Hung and Ciuffreda (1991) used the same instrument and protocol to examine tonic accommodation in high and low myopes, emmetropes and hyperopes. The former study found no difference between refractive groups, while the latter study reported greater tonic accommodation in high myopes and emmetropes than hyperopes and low myopes. Inter-subject variations may therefore result in different findings.

There was no difference in tonic accommodation among PM, SM and emmetropes in the present study. This did not support the findings by previous studies (Gawron, 1981; Tokoro, 1988; Jiang and Morse, 1999; Vera-Diaz et al., 2000). Jiang and Morse (1999) showed higher tonic accommodation in PM than SM and emmetropes, while Vera-Diaz (2000) found PM and emmetropes had higher tonic accommodation than SM. Jiang and Morse (1999) used different refractive corrections, either soft contact lens or trial lens for their subjects. It is not clear if lens effectivity was considered. Vera-Diaz (2000) did not specify their measuring condition.

11.1.3. Non-Chinese adults versus Chinese adults

11.1.3.a. Results

The mean tonic accommodation of non-Chinese and Chinese adults were 1.00 ± 0.52 D and 1.01 ± 0.50 D respectively. There was no significant difference between ethnic groups (Two-way ANCOVA with age set as covariate, $F_{(1, 73)} = 0.12$, $p > 0.05$) and refractive groups ($F_{(1,73)} = 1.05$, $p > 0.05$), and no significant interaction between ethnic and refractive groups ($F_{(1, 73)} = 0.01$, $p > 0.05$).

11.1.3.b. Discussion

Tonic accommodation of Chinese has not been studied before and there is no literature reporting the tonic accommodation in different ethnic groups using the same protocol. The current results imply that the high prevalence of myopia found in Chinese population is not related to tonic accommodation.

11.2. Chinese children

11.2.1. Cross-sectional study

11.2.1.a. Results

The mean (± SD) tonic accommodation in the cross-sectional study for emmetropes and myopes was 0.71 ± 0.57 D and 0.40 ± 0.43 D respectively. There was no statistically significant difference between the two groups (One-way ANCOVA with age set as covariate, $F_{(1,28)} = 3.90$, $p > 0.05$).

11.2.1.b. Discussion

The present statistical finding was similar to that observed by Wolffsohn et al. (2003) (including the present author), which also used a modified Shin-Nippon SRW-5000 auto-refractor with a DOG grating to measure the tonic accommodation in Chinese children. However, when look at the value of tonic accommodation of each refractive group, myopes had lower value than emmetropes. The difference in tonic accommodation (0.31 D) between them was more than 0.25 D and could have clinical significance. The difference failed to reach a statistically significant level could be due to the small number of emmetropes (n = 8). More emmetropes should be recruited for future investigation.

The current trend was similar to those reported by other studies (Rosner and Rosner, 1989; Gwiazda et al., 1995b; Yap et al., 1998; Chat, 2001) which found that myopic children had lower tonic accommodation than emmetropic children, despite of different methods used to measure tonic accommodation, different subject age ranges and different refractive group criteria (see Table 4.1., Chapter 4). The method used in this study eliminated the problems occurred in the above mentioned studies like the drawback of the use of retinoscopy in Rosner and Rosner (1989), the wide age range of subjects and unwanted effect of trials lens in Gwiazda et al. (1995b) and drawback of empty field method in Woung et al. (1998). Rosner and Rosner (1989) used dynamic retinoscopy with a DOG grating target. Their young subjects might look at the retinocsopic light rather than the DOG grating during the experiment which would stimulate blur-driven and proximal-induced accommodation (Rosenfield et al., 1993). Further, the authors did not consider inter-examiner variability and the accuracy of the experimental results were therefore doubtful. Gwiazda et al. (1995b) recruited subjects with a wider age range (6.5 to 16.5 years) and this would influence the results as tonic accommodation has been shown to decrease with age (Whitefoot and Charman, 1992; Mordi and Ciuffreda, 1998). Their trial lenses used for correcting the refractive error were placed at a forward tilt of 15 degrees. This would create unwanted astigmatism and alter the spherical power, decreasing accommodative demand by an average of 6 % (Gwiazda et al., 1993; Ong and Ciuffreda, 1997).

In order to facilitate comparison of tonic accommodation in various studies, the accommodative response should be referred to the same reference plane, either spectacle or ocular plane (Fisher et al., 1987). Therefore lens effectivity should be taken into consideration before presenting the tonic accommodation in different refractive groups. Yap et al. (1998) and Zadnik et al. (1999) did not specify if trial lens or contact lens were used, or whether any correction had been given during the experiment. Woung et al. (1998) provided stimulus-free conditions by the bright empty field method. It is difficult to make sure that any stimulus for blur (for example, texture imperfections or luminance variations in the screen surface) or proximal accommodation is absent (Rosenfield et al., 1993). Chat (2001) also measured tonic accommodation in Chinese children. Subjects in her study were asked to look straight ahead in complete darkness without any refractive error correction. The accommodative responses were then adjusted and recorded with respect to the refractive error, and tonic accommodation was presented in sphero-cylinder format. The current experiment provides additional advantages over the other studies (Rosner and Rosner, 1989; Gwiazda et al., 1995b; Woung et al., 1998; Yap et al., 1998; Zadnik et al., 1999; Chat, 2001) as tonic accommodation was measured in continuous mode, giving a potentially more reliable result.

Subjects in Chat (4 to 8 years) and Wolffsohn et al. (6 to 12 years) studies were younger than those in current studies (10 to 12 years). Tonic accommodation has been reported to reduce with age (Whitefoot and Charman, 1992; Mordi and Ciuffreda, 1998). Comparison in tonic accommodation in different refractive groups between current and other studies would be difficult if the age ranges of their subjects are different.

11.2.2. Longitudinal study

11.2.2.a. Results

Since the tonic accommodation from emmetropes and myopes had different standard deviations in Visit A ($p < 0.05$), a non-parametric test was used in analysing the results from the longitudinal study. However, there is no non-parametric test equivalent to 2-way repeated measures ANOVA. Due to the limitations of non-parametric test, analysis could not be done with the control of age, as can be done using the parametric 2-way repeated measures ANCOVA. Friedman's test for K-related samples was used to test changes between repeated measures for each refractive groups, and Mann-Whitney U test was used to test differences between groups. Significance level of Mann-Whitney U test was adjusted by the number of tests done, i.e. 0.05/3, as doing the non-parametric test three times would inflate type I error. The tonic accommodation of emmetropes was similar to that of myopes at all visits (Table 11.2.2.a.1.) (Mann-Whitney test, $p > 0.05/3$). There was an increase in mean tonic accommodation between visits in myopes (Friedman test, $p < 0.05$). Post-hoc testing (Dunn's post-test) showed significant differences in responses between Visits A and C ($p < 0.05$). However, when the change in tonic accommodation was plotted against the change in refractive error in myopes, the correlation was not statistically significant ($r = 0.41$, $p > 0.05$) (Figure 11.2.2.a.1). Tonic accommodation of emmetropes remained similar during the longitudinal study (Friedman test, $p > 0.05$) [c].

[c] Two-way repeated measures ANCOVA, with age set as covariate, was carried out disregarding the difference in SD between groups in Visit A. Tonic accommodation of both groups remained constant throughout the study ($F_{(2,38)} = 0.34$, $p > 0.05$). Emmetropes had similar tonic

	Visit A	Visit B	Visit C
Emmetropes (n = 6)	0.72 ± 0.67 D	1.01 ± 0.39 D	0.97 ± 0.38 D
Myopes (n = 16)	0.41 ± 0.38 D	0.64 ± 0.52 D	0.91 ± 0.42 D

Table 11.2.2.a.1. The mean (± SD) tonic accommodation of Chinese children in Visits A, B and C.

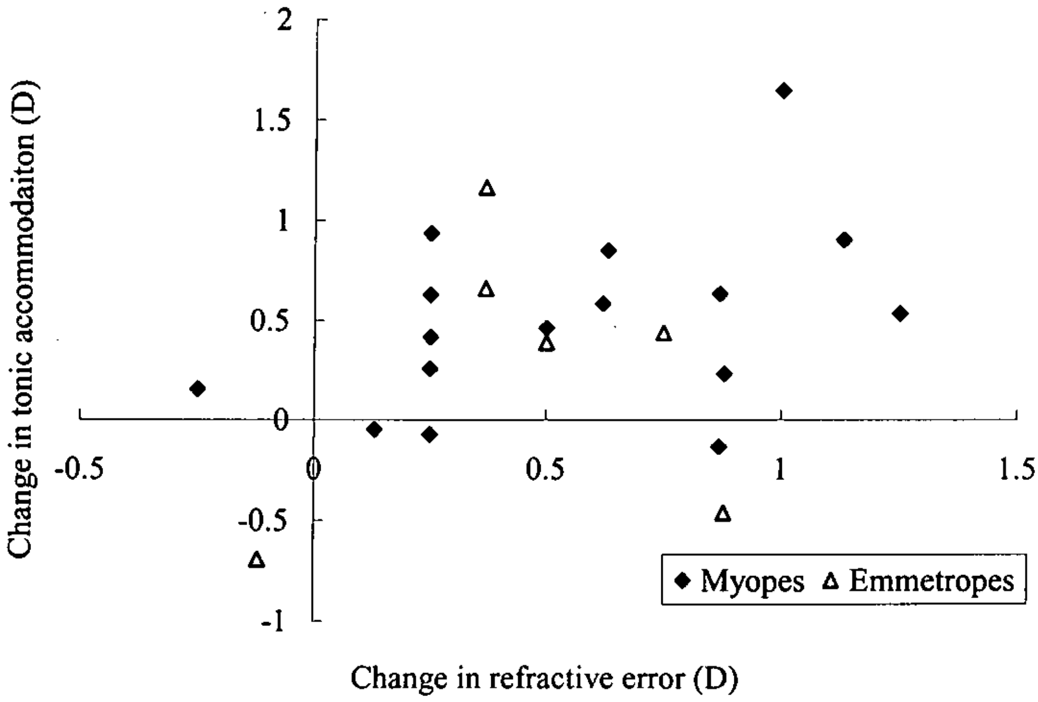

Figure 11.2.2.a.1. Individual change in tonic accommodation (n = 22) as a function of change in refractive error (positive indicates more myopic). The Pearson correlation coefficient r for emmetropes and myopes are 0.15 and 0.41 respectively, $p > 0.05$.

Half of the emmetropes (n = 3) in the current study became myopic during the longitudinal study and the tonic accommodation before and after onset of myopia

accommodation with myopes at all visits ($F_{(1,19)} = 1.46$, $p > 0.05$). There was no interaction between visits and refractive groups ($F_{(2,38)} = 0.67$, $p > 0.05$).

for this group of subjects, and for subjects who remained emmetropic is tabulated in Table 11.2.2.a.2.

	Visit A	Visit C
EMM_EMM (n = 3)	0.48 ± 0.52 D	0.85 ± 0.45 D
EMM_M (n = 3)	0.96 ± 0.83 D	1.08 ± 0.34 D

Table 11.2.2.a.2. The mean (± SD) tonic accommodation of child emmetropes who remained emmetropic (EMM_EMM) and became myopic (EMM_M) at the end of the longitudinal study.

No statistical test was done to compare the tonic accommodation of emmetropes who remained emmetropic (EMM_EMM) and became myopic (EMM_M) at the end of the longitudinal study due to small subject number in each group.

11.2.2.b. Discussion

Tonic accommodation of child emmetropes remained unchanged throughout the longitudinal study By simply looking at the value of tonic accommodation at each visit, they had their tonic accommodation increased from Visits A to C. This difference failed to reach a significant level might be due to small subject number. Therefore more emmetropes should be recruited for future study. Tonic accommodation of myopes increased from Visit A to Visit C and the change was not related to the change in refractive error. As the subject numbers of EMM_M and EMM_EMM were small, no statistical test was done to compare their tonic accommodation. By simply looking at the mean tonic accommodation of

EMM_M and EMM_EMM, the former group had greater tonic accommodation than the latter group throughout the study. However, the variances were high for both groups, especially in Visit A, so it was difficult to draw any conclusion. More emmetropes should be recruited for future work.

11.3. Chinese adults versus children

11.3.1. Results

During the cross-sectional study, Chinese adults (1.02 ± 0.50 D) exhibited greater tonic accommodation than Chinese children (0.48 ± 0.48 D) (Two-way ANOVA, $F_{(1, 70)} = 13.87$, $p < 0.001$). There was no statistically significant difference between refractive groups (Two-way ANOVA, $F_{(1,70)} = 2.91$, $p > 0.05$) and there was no significant interaction between refractive groups and age groups (Two-way ANOVA, $F_{(1,70)} = 0.56$, $p > 0.05$).

11.3.2. Discussion

These finding are different from those of Rosenfield et al. (1994) who found that tonic accommodation was similar in children and young adults. It is strange to find a greater tonic accommodation in adults here because tonic accommodation should decrease with age (Whitefoot and Charman, 1992; Mordi and Ciuffreda, 1998). Is the previously reported relationship between tonic accommodation and age on non-Chinese not applicable to Chinese? Since there has been no similar study in Chinese subjects before, there is no literature for comparison. In the present study, children had lower tonic accommodation than adults which may suggest why children are more susceptible to myopia than the latter group (Adams and McBrien, 1993; Woung et al., 1993). Van Alphen (1961) suggested subject with low tonic accommodation would be more affected by the variations in intra-ocular pressure, resulting in scleral stretching.

11.4. Summary

1. There was no difference in tonic accommodation between emmetropes and myopes (either LOM, EOM, PM or SM) in either non-Chinese or Chinese adults. The proposal that LOM have lower parasympathetic innervation than emmetropes leading to a reduction in tonic accommodation (McBrien and Millodot, 1987) could not be substantiated here.

2. Tonic accommodation of non-Chinese and Chinese adults was similar, so its variation is unlikely to be the cause of high prevalence of myopia in Chinese.

3. Child emmetropes had similar tonic accommodation as myopes.

4. Tonic accommodation of child emmetropes had a trend of increasing throughout the longitudinal visits, while that of child myopes increased

across visits. The change in tonic accommodation for myopes was not related to change in refractive error.

Chapter 12. Nearwork-induced transient myopia (NITM)

Most of the previous studies reported NITM in the first 10-seconds post-task (Ciuffreda and Wallis, 1998; Ciuffreda and Lee, 2002), while a more recent study reported NITM at both the 10th and 30th second post-task (Vera-Diaz et al., 2002). The mean NITM in the first 10-seconds (1st to 10th second), the third 10-seconds (21st to 30th second), the first minute (1st to 60th second), second minute (61st to 120th second) and third minute (121st to 180th second) after task cessation were presented in this chapter. These time periods were chosen as the first 10-seconds represents the initial NITM, and the third 10-seconds represents a more stabilised response. Both the former and latter time periods could be used for direct comparison with the literature. For the reporting of the first, second and third minutes time periods, they facilitated the investigation of whether NITM eventually decays to zero after task. Unless specified, 2-way ANOVA and 2-way repeated measures ANOVA were used for data analysis. For two-way ANOVA tests, refractive groups and stimuli (5.0 D and 2.5 D) were set as independent variables to investigate the effect of refractive groups and the use of different stimuli on NITM in the first 10-seconds and the third 10-seconds post-change, and any possible interaction between these two factors. For two-way repeated measures ANOVA, refractive groups and time were set as independent variables to study the effect of time (the first, second and third minutes time periods), refractive groups and their interaction on the relaxation of NITM. As reported in Section 8.1.3., Chinese adults were older than non-Chinese adults and myopic children were older than emmetropic children. There is no previous study reporting the effect of age on NITM. In order to avoid any effect of age on NITM, if any, analysis of covariance (ANCOVA) with age set as covariate was used to compare NITM between Chinese and non-Chinese adults and emmetropic and myopic children.

12.1. Adults

12.1.1. Non-Chinese adults

12.1.1.a. Results

The mean NITM in the first 10-seconds, the third 10-seconds, the first, second and third minutes after task removal are listed in Table 12.1.1.a.1. For NITM in the first 10-seconds post-change, there were no significant differences between refractive groups ($F_{(1,66)} = 0.19$, $p > 0.05$) or between stimuli ($F_{(1,66)} = 0.23$, $p > 0.05$), and no statistically significant interaction between refractive groups and stimuli ($F_{(1,66)} = 0.20$, $p > 0.05$). For NITM in the third 10-seconds post-change, there were no significant differences between refractive groups ($F_{(1,66)} = 0.86$, $p > 0.05$) or between stimuli ($F_{(1,66)} = 0.79$, $p > 0.05$). However, the interaction between refractive groups and stimuli was significant ($F_{(1,66)} = 7.70$, $p < 0.05$). This indicates the influence of stimulus level on NITM was different for emmetropes and myopes. Emmetropes had greater NITM than myopes after the 5.0 D task, but lower NITM than myopes after the 2.5 D task. The difference in NITM between emmetropes and myopes was greater after the 2.5 D than after the 5.0 D tasks (Figure 12.1.1.a.1), and the difference in NITM between 5.0 D and 2.5 D was greater in emmetropes than in myopes (Figure 12.1.1.a.2).

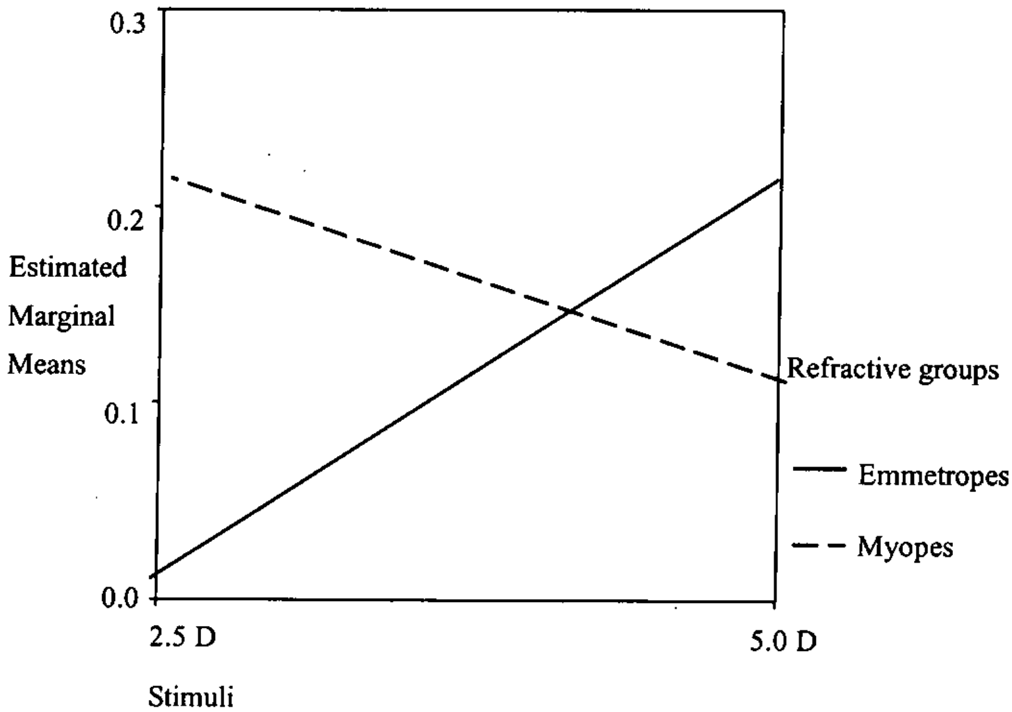

Figure 12.1.1.a.1. Interaction plot with refractive groups against stimuli.

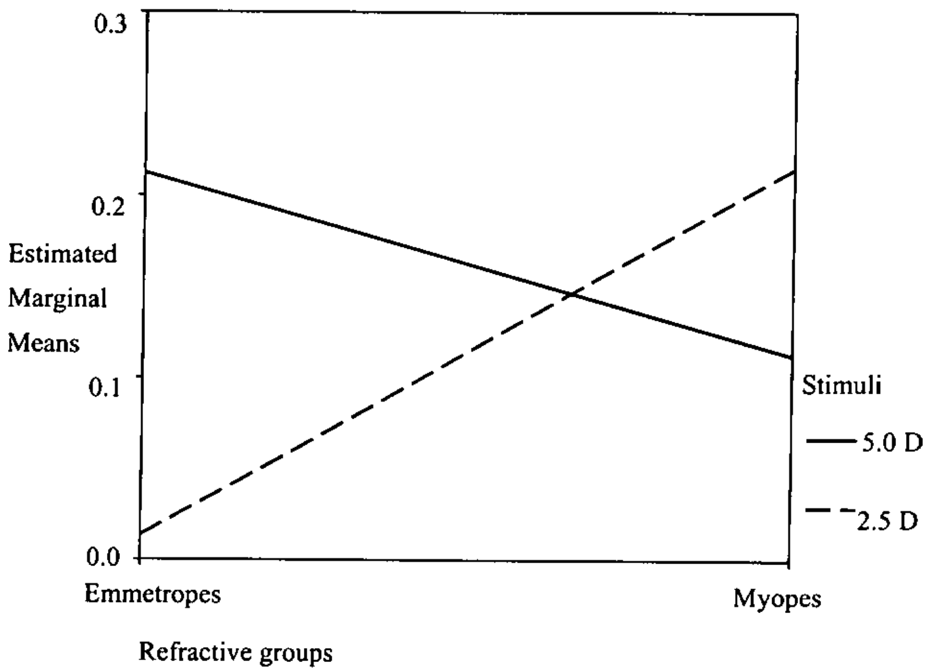

Figure 12.1.1.a.2. Interaction plot with stimuli against refractive groups.

	1st 10-seconds post-change	3rd 10-seconds post-change	1st minute post-change	2nd minute post-change	3rd minute post-change
			Emmetropes (n=17)		
Task A (5.0 D to 0.0 D)	0.33 ± 0.33 D**	0.21 ± 0.27 D**	0.22 ± 0.28 D**	0.08 ± 0.30 D	0.11 ± 0.30 D
Task B (2.5 D to 0.0 D)	0.34 ± 0.32 D**	0.01 ± 0.26 D	0.10 ± 0.23 D	− 0.01 ± 0.19 D	− 0.06 ± 0.17 D
			Myopes (n=18)		
Task A (5.0 D to 0.0 D)	0.27 ± 0.29 D**	0.11 ± 0.19 D**	0.07 ± 0.20D	-0.02 ± 0.19 D	0.00 ± 0.20 D
Task B (2.5 D to 0.0 D)	0.34 ± 0.21 D**	0.21 ± 0.18 D**	0.19 ± 0.13 D**	0.01 ± 0.11 D	0.01 ± 0.14 D

Table 12.1.1.a.1. The mean (± SD) NITM of non-Chinese adults during the first three minutes post-change. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

Two-way repeated measures ANOVA (with refractive groups and time set as independent variables) demonstrated different NITM at different times post-change after 5.0 D and 2.5 D tasks (5.0 D: $F_{(2, 66)} = 8.39$, $p < 0.05$; 2.5 D: $F_{(2, 66)} = 24.69$, $p < 0.001$). "Contrasts" function showed different NITM between the first and second minutes only (5.0 D: $F_{(1, 33)} = 32.05$, $p < 0.001$; 2.5 D: $F_{(1, 33)} = 34.58$, $p < 0.001$). Both emmetropes and myopes had similar accommodation in the first, second and third minutes post-change (5.0 D: $F_{(1, 33)} = 2.67$, $p > 0.05$; 2.5 D: $F_{(1, 33)} = 1.54$, $p > 0.05$). There was no interaction effect between refractive groups and time (5.0 D: $F_{(2, 66)} = 0.40$, $p > 0.05$; 2.5 D: $F_{(2, 66)} = 0.79$, $p > 0.05$).

Myopes were divided into sub-groups based on age of myopic onset and progression of myopia according to criteria previously described in Chapter 9. NITM of LOM, EOM and emmetropes are listed in Table 12.1.1.a.2, while that of PM, SM and emmetropes are listed in Table 12.1.1.a.3. Due to small sample size in different sub-groups, statistical analysis was not performed.

	1st 10-seconds post-change	3rd 10-seconds post-change	1st minute post-change	2nd minute post-change	3rd minute post-change
			LOM (n=4)		
Task A (5.0 D to 0.0 D)	0.17 ± 0.34 D	0.02 ± 0.15 D	– 0.04 ± 0.20 D	– 0.11 ± 0.27 D	– 0.03 ± 0.23 D
Task B (2.5 D to 0.0 D)	0.49 ± 0.28 D	0.28 ± 0.20 D	0.25 ± 0.11 D	– 0.01 ± 0.01 D	0.00 ± 0.05 D
			EOM (n=14)		
Task A (5.0 D to 0.0 D)	0.30 ± 0.28 D	0.14 ± 0.20 D	0.10 ± 0.19 D	0.00 ± 0.17 D	0.00 ± 0.20 D
Task B (2.5 D to 0.0 D)	0.30 ± 0.17 D	0.20 ± 0.18 D	0.17 ± 0.13 D	0.02 ± 0.13 D	0.01 ± 0.16 D
			Emmetropes (n=17)		
Task A (5.0 D to 0.0 D)	0.33 ± 0.33 D**	0.21 ± 0.27 D**	0.22 ± 0.28 D**	0.08 ± 0.30 D	0.11 ± 0.30 D
Task B (2.5 D to 0.0 D)	0.34 ± 0.32 D**	0.01 ± 0.26 D	0.10 ± 0.23 D	– 0.01 ± 0.19 D	– 0.06 ± 0.17 D

Table 12.1.1.a.2. The mean (± SD) NITM of non-Chinese adult late-onset myopes, early-onset myopes and emmetropes during the first three minutes post-change. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

LOM: Late-onset myopes; EOM: Early-onset myopes.

	1st 10-seconds post-change	**3rd 10-seconds post-change**	**1st minute post-change**	**2nd minute post-change**	**3rd minute post-change**
			PM (n=10)		
Task A (5.0 D to 0.0 D)	0.21 ± 0.25 D	0.09 ± 0.19 D	0.04 ± 0.20 D	– 0.03 ± 0.20 D	– 0.02 ± 0.22 D
Task B (2.5 D to 0.0 D)	0.40 ± 0.19 D	0.25 ± 0.20 D	0.22 ± 0.12 D	0.00 ± 0.12 D	0.01 ± 0.14 D
			SM (n=8)		
Task A (5.0 D to 0.0 D)	0.35 ± 0.33 D	0.14 ± 0.20 D	0.10 ± 0.20 D	– 0.02 ± 0.20 D	0.01 ± 0.19 D
Task B (2.5 D to 0.0 D)	0.26 ± 0.21 D	0.18 ± 0.15 D	0.15 ± 0.14 D	0.03 ± 0.11 D	0.01 ± 0.15 D
			Emmetropes (n=17)		
Task A (5.0 D to 0.0 D)	0.33 ± 0.33 D**	0.21 ± 0.27 D**	0.22 ± 0.28 D**	0.08 ± 0.30 D	0.11 ± 0.30 D
Task B (2.5 D to 0.0 D)	0.34 ± 0.32 D**	0.01 ± 0.26 D	0.10 ± 0.23 D	– 0.01 ± 0.19 D	– 0.06 ± 0.17 D

Table 12.1.1.a.3. The mean (± SD) NITM of non-Chinese adult progressing myopes, stable myopes and emmetropes during the first three minutes post-change in NITM study. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level. PM: Progressing myopes; SM: Stable myopes.

NITM among LOM, EOM and emmetropes

Both LOM and EOM demonstrated a trend of decreasing NITM from the first 10-seconds towards the third minute. In LOM, the NITM was greater after the 2.5 D task than that after the 5.0 D task at different time intervals, and had their NITM returned to zero faster with the 5.0 D task. In EOM, the NITM was greater after the 2.5 D task than that after the 5.0 D task at the third 10-seconds and the first one minute. For the other time intervals, the NITM was similar between the two tasks.

NITM among PM, SM and emmetropes

Both PM and SM demonstrated a trend of decreasing NITM from the first 10-seconds towards the third minute. In PM, a greater difference in NITM was found between the 2.5 D and 5.0 D tasks at the first 10-seconds, third 10-seconds and the first one minute. In SM, the NITM difference was smaller between the two tasks at different time intervals compared with that in PM.

12.1.1.b. Discussion

Advantages of the current method over the others

Previous studies have demonstrated different NITM in different refractive groups (Ciuffreda and Wallis, 1998; Ciuffreda and Lee, 2002; Vera-Diaz et al., 2002). Different methodologies in measuring accommodative response certainly affect the results obtained. The method used in the current study has the following advantages. Accommodative responses of the subjects were measured in a continuous mode with 60 readings captured in one second. In calculating the NITM after the 5.0 D task (Task A), the distant accommodative response (D2) during distant viewing in Task C was treated as the baseline accommodation during relaxation. The difference between the accommodative response after near target removal in Task A (D1) and D2 was considered as the NITM (see Section 7.4.4., Chapter 7). In calculating NITM after the 2.5 D task, Task D and Task B results were used. The response D2 was the averaged accommodation measured over 5 minutes of distant viewing. In contrast, other studies also subtract the post-change accommodative response from the pre-change accommodative level, but they only measured 20 to 30 pre-change readings by asking their subjects to fixate at 4 m or 6 m for a duration of 40 to 60 seconds (Ciuffreda and Wallis, 1998; Ciuffreda and Lee, 2002; Vera-Diaz et al., 2002). The distant accommodative response measured by previous methods might not be truly reflecting the distant accommodative response compared with the current method, and thus alter the NITM readings.

Comparison between emmetropes and myopes

The current study showed that myopes and emmetropes had similar NITM in first 10-seconds and the third 10-seconds post-change regardless of the accommodative demand. There was no dose effect demonstrated in NITM. NITM in both myopes and emmetropes had decayed to nearly baseline values after the first minute post-change. Post-hoc testing showed significant NITM between the first and second minutes. This suggests that accommodation relaxed after task removal was not completed in the first minute but became fully relaxed from the second minute onward. NITM experienced by emmetropes in the current study was unexpectedly high, resulting in no statistical difference between refractive groups. No comparison with the literature was done as there is no previous study on NITM comparing adult emmetropes and myopes. The only study comparing NITM after 3.0 D and 5.0 D stimuli by Ciuffreda et al. (1996) also showed similar NITM immediately after task removal between the two accommodative demands.

Comparison between emmetropes and myopic sub-groups

The results for LOM, EOM and emmetropes in the present study were not compared with the literature as the number of subjects recruited in each sub-group was small.

Vera-Diaz et al. (2002) found a greater NITM in PM than in SM and emmetropes at the 10th second or 30th second post-change. PM took three times longer (> 120 seconds) than SM (42 seconds) and emmetropes (35 seconds) to have their NITM decayed back to baseline levels. They suggested that the classification according to the age of onset of myopia would underestimate the mean NITM as progression of myopia might occur in some of the EOM and not in LOM. The current study found similar NITM in the first 10-seconds for SM and emmetropes. Comparing PM with SM and emmetropes, the result was dose dependent with NITM after the 2.5 D task greater than that after the 5.0 D from

PM. At the third 10-seconds, dose effects occurred in both PM and emmetropes. All these subjects had their NITM decayed to baseline after the first minute post-task. The only study to have shown similar NITM among different refractive groups was carried out by Fisher and co-workers (Fisher et al., 1987). Their results could not be compared with the present one as they recruited low myopes, high myopes, emmetropes and hyperopes.

It is difficult to compare the current NITM findings with other studies because different near task durations and accommodative demands were used. The near task duration used in this study was 5 minutes which was shorter than that in other studies (Fisher et al., 1987; Ciuffreda and Wallis, 1998; Ciuffreda and Lee, 2002; Vera-Diaz et al., 2002). The current study involved 4 NITM experimental paradigms, each lasting for a total of 8 minutes. In order to monitor the accommodative response change, subjects were required to have their head steadied on the chin rest and maintained good fixation throughout each task. It was therefore not possible to ask the subjects to perform each task for any longer, such as 10 minutes to 4 hours as in other studies. Previous studies (Ciuffreda et al., 1996; Wolffsohn et al., 2003a) have found significant NITM after as short as 4- to 5-minute near task. NITM experienced by emmetropes in the current study was unexpectedly high, resulting in no difference between refractive groups. For example, the average NITM of emmetropes was 0.33 D and 0.34 D in the first 10-seconds post-change after the 5.0 D and the 2.5 D tasks respectively. Previous studies found NITM less than 0.20 D for up to 4 hours of the 5.0 D near task (Ciuffreda and Wallis, 1998; Vera-Diaz et al., 2002).

The current experiment did not look at the time constant of NITM decay, which can determine the time at which subject's NITM decayed back to baseline levels. Determination of this time constant in future work would facilitate comparison with previous results (Ciuffreda and Wallis, 1998; Vera-Diaz et al., 2002) and provide a more complete picture of NITM.

12.1.2. Chinese adults

12.1.2.a. Results

The mean NITM in the first 10-seconds, the third 10-seconds, the first, second and third minutes after task removal are listed in Table 12.1.2.a.1. For NITM in the first 10-seconds post-change, there were no significant differences in NITM between refractive groups ($F_{(1,82)} = 0.14$, $p > 0.05$) or between stimuli ($F_{(1,82)} = 0.73$, $p > 0.05$), and no statistically significant interaction between refractive groups and stimuli ($F_{(1,82)} = 0.35$, $p > 0.05$). For NITM in the third 10-seconds post-change, there were no significant differences in NITM between refractive groups ($F_{(1,82)} = 0.01$, $p > 0.05$) or between stimuli ($F_{(1,82)} = 1.76$, $p > 0.05$). There was a significant interaction between refractive groups and stimuli ($F_{(1,82)} = 4.46$, $p < 0.05$). Differences in NITM between 5.0 D and 2.5 D were greater in myopes than in emmetropes (Figure 12.1.2.a.1). NITM of myopes was greater than that of emmetropes after the 5.0 D task, but lower than that of emmetropes after the 2.5 D task (Figure 12.1.2.a.2).

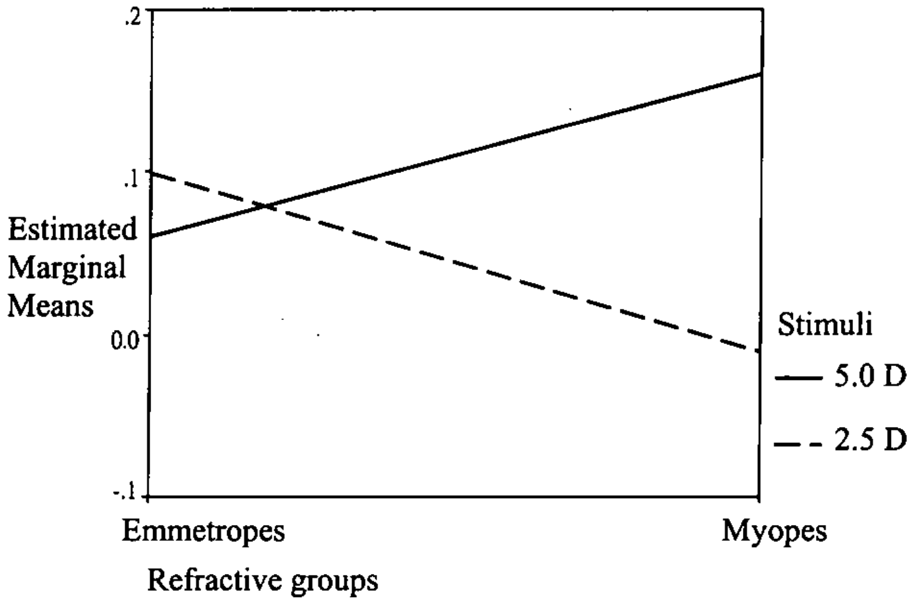

Figure 12.1.2.a.1. Interaction plot with stimuli against refractive groups.

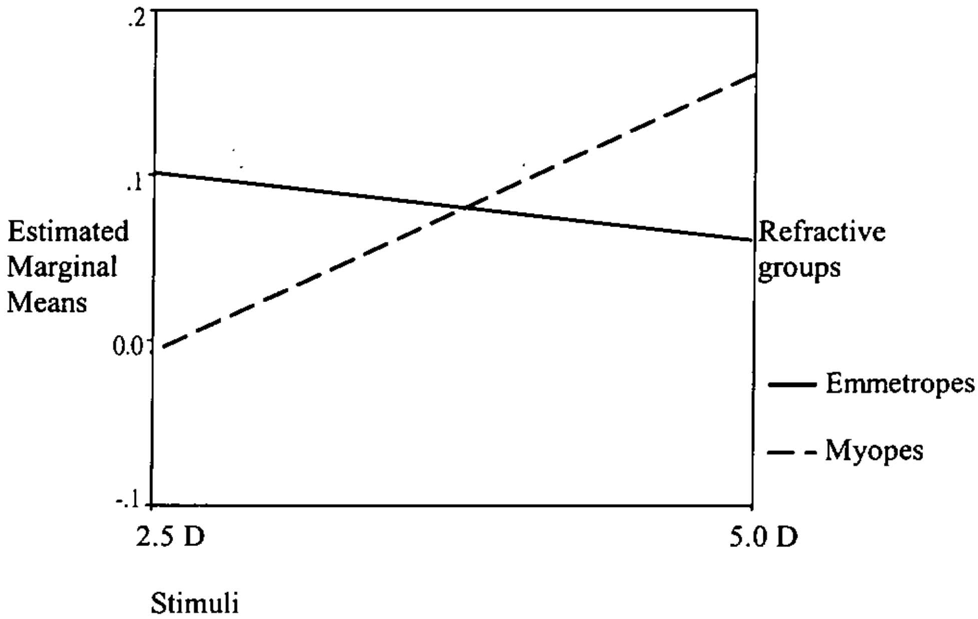

Figure 12.1.2.a.2. Interaction plot with refractive groups against stimuli

	1st 10-seconds post-change	3rd 10-seconds post-change	1st minute post-change	2nd minute post-change	3rd minute post-change
	Emmetropes (n=21)				
Task A (5.0 D to 0.0 D)	0.30 ± 0.25 D**	0.06 ± 0.20 D	0.10 ± 0.19 D **	-0.01 ± 0.21 D	-0.01 ± 0.22 D
Task B (2.5 D to 0.0 D)	0.28 ± 0.24 D**	0.10 ± 0.19 D**	0.08 ± 0.17 D **	-0.03 ± 0.17 D	0.04 ± 0.22 D
	Myopes (n=22)				
Task A (5.0 D to 0.0 D)	0.31 ± 0.37 D**	0.16 ± 0.34 D**	0.13 ± 0.28 D **	0.01 ± 0.22 D	-0.02 ± 0.20 D
Task B (2.5 D to 0.0 D)	0.22 ± 0.28 D**	–0.01 ± 0.13 D	0.04 ± 0.13 D	-0.03 ± 0.15 D	0.02 ± 0.12 D

Table 12.1.2.a.1. The mean (± SD) NITM of Chinese adults during the first three minutes post-change. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

Two-way repeated measures ANOVA (with refractive groups and time set as independent variables) demonstrated different NITM at different times post-change after 5.0 D and 2.5 D tasks (5.0 D: $F_{(2, 82)} = 19.53$, $p < 0.001$; 2.5 D: $F_{(2, 82)} = 12.26$, $p < 0.001$). "Contrasts" function showed different NITM in the first and second minutes post-change after both tasks ($p < 0.001$). Emmetropes and myopes had similar accommodation in the first, second and third minutes post-change after 5.0 D or 2.5 D tasks (5.0 D: $F_{(1,41)} = 0.05$, $p > 0.05$; 2.5 D: $F_{(1,41)} = 0.21$, $p > 0.05$). There was no interaction effect between refractive groups and time (5.0 D: $F_{(2, 82)} = 0.48$, $p > 0.05$; 2.5 D: $F_{(2, 82)} = 0.56$, $p > 0.05$).

Myopes were divided into sub-groups based on the age of myopia onset and progression of myopia according to criteria previously described in Chapter 9. NITM of LOM, EOM and emmetropes are listed in Table 12.1.2.a.2, and those of PM, SM and emmetropes are listed in Table 12.1.2.a.3. Statistical analysis was not performed due to the small sample size.

	1st 10-seconds post-change	3rd 10-seconds post-change	1st minute post-change	2nd minute post-change	3rd minute post-change
			LOM (n=9)		
Task A (5.0 D to 0.0 D)	0.38 ± 0.52 D	0.14 ± 0.44 D	0.14 ± 0.38 D	– 0.06 ± 0.21 D	-0.08 ± 0.20 D
Task B (2.5 D to 0.0 D)	0.24 ± 0.38 D	–0.03 ± 0.18 D	0.00 ± 0.17 D	-0.08 ± 0.18 D	0.00 ± 0.11 D
			EOM (n=13)		
Task A (5.0 D to 0.0 D)	0.27 ± 0.24 D	0.17 ± 0.27 D	0.13 ± 0.21 D	0.06 ± 0.23 D	0.03 ± 0.20 D
Task B (2.5 D to 0.0 D)	0.21 ± 0.20 D	0.00 ± 0.09 D	0.07 ± 0.09 D	0.00 ± 0.12 D	0.04 ± 0.12 D
			Emmetropes (n=21)		
Task A (5.0 D to 0.0 D)	0.30 ± 0.25 D**	0.06 ± 0.20 D	0.10 ± 0.19 D **	-0.01 ± 0.21 D	-0.01 ± 0.22 D
Task B (2.5 D to 0.0 D)	0.28 ± 0.24 D**	0.10 ± 0.19 D**	0.08 ± 0.17 D **	-0.03 ± 0.17 D	0.04 ± 0.22 D

Table 12.1.2.a.2. The mean (± SD) NITM of Chinese adult late-onset myopes, early-onset myopes and emmetropes during the first 3 minutes post-change. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level. LOM: Late-onset myopes; EOM: Early-onset myopes.

	1st 10-seconds post-change	**3rd 10-seconds post-change**	**1st minute post-change**	**2nd minute post-change**	**3rd minute post-change**
			PM (n=5)		
Task A (5.0 D to 0.0 D)	0.53 ± 0.62 D	0.37 ± 0.49 D	0.29 ± 0.41 D	0.05 ± 0.18 D	0.01 ± 0.19 D
Task B (2.5 D to 0.0 D)	0.47 ± 0.37 D	0.03 ± 0.22 D	0.10 ± 0.11 D	0.00 ± 0.19 D	0.08 ± 0.12 D
			SM (n=17)		
Task A (5.0 D to 0.0 D)	0.25 ± 0.26 D	0.10 ± 0.28 D	0.09 ± 0.23 D	0.00 ± 0.24 D	– 0.02 ± 0.21 D
Task B (2.5 D to 0.0 D)	0.15 ± 0.21 D	– 0.02 ± 0.10 D	0.03 ± 0.14 D	– 0.04 ± 0.14 D	0.00 ± 0.11 D
			Emmetropes (n=21)		
Task A (5.0 D to 0.0 D)	0.30 ± 0.25 D**	0.06 ± 0.20 D	0.10 ± 0.19 D **	-0.01 ± 0.21 D	-0.01 ± 0.22 D
Task B (2.5 D to 0.0 D)	0.28 ± 0.24 D**	0.10 ± 0.19 D**	0.08 ± 0.17 D **	-0.03 ± 0.17 D	0.04 ± 0.22 D

Table 12.1.2.a.3. The mean (± SD) NITM of Chinese adult progressing myopes, stable myopes and emmetropes during the first 3 minutes post-change in NITM study. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

PM: Progressing myopes; SM: Stable myopes.

NITM among LOM, EOM and emmetropes

Both LOM and EOM showed a faster decay in NITM after the 2.5 D task compared with the 5.0 D task. Their NITM returned to baseline from the third 10-seconds. The NITM during the first 10-seconds were similar among LOM, EOM and emmetropes. For other time intervals, it depended upon the dose.

NITM among PM, SM and emmetropes

PM had greater NITM than SM at different time intervals. Both PM and SM had a faster decay in NITM at the 2.5 D task compared with the 5.0 D task. The NITM returned to almost baseline at the third 10-seconds after the 2.5 D task for both PM and SM.

12.1.2.b. Discussion

Comparison between emmetropes and myopes

No previous study has investigated NITM in Chinese adults. This study showed similar NITM in the first 10-seconds or the third 10-seconds post-change in myopes and emmetropes regardless of task demand. There was no dose effect demonstrated in NITM, similar to the findings with non-Chinese adults. Both myopes and emmetropes had their NITM decayed to nearly baseline levels after the first minute post-change. This suggested that accommodation relaxed after task removal in the first minute and then became stable in the second minute onward. Fisher et al. (1987) has reported that NITM was similar among low myopes, high myopes, emmetropes and hyperopes. Ciuffreda et al. (1996) also showed similar NITM immediately after task removal between two accommodative demands (3.0 D and 5.0 D).

Comparison between emmetropes and myopic sub-groups

The NITM following the 5.0 D task decayed to baseline faster in LOM than EOM, followed by emmetropes. On the other hand, the different refractive group's had their NITM decayed to baseline following the 2.5 D task at a similar speed. Vera-Diaz et al. (2002) had measured NITM in LOM, EOM and emmetropes before and reported a similar finding. Ciuffreda and Wallis (1998) found a greater NITM in myopes than emmetropes, in which LOM and EOM had similar NITM in the first 10-seconds post-change but LOM took a longer time (63 seconds) than EOM (35 seconds) for their NITM to decay back to the baseline. They proposed that LOM had a weaker sympathetic innervation making them more susceptible to the development of myopia due to environmental factors, such as nearwork. This would cause cumulative transient increase in myopic retinal defocus over time, and the situation would be more serious if a greater lag of accommodation also occurred during near fixation. It could be hypothesised that such defocus would cause the progression of myopia, not withstanding that it might be within one's depth of focus and lack a blur directional signal. The present study found similar NITM in different refractive groups. Ciuffreda and Lee (2002) carried out another study in which they asked their subjects to perform normal reading tasks for 4 hours. They found greater

NITM in the first 10-seconds post-change in myopes than in emmetropes. Although their EOM had similar NITM with LOM, the NITM in the latter group lasted longer. Their near tasks were performed at the subject's habitual working distance. This inevitably varied between individuals and hence the near accommodation demand could be difficult to control. No information was provided about refractive error correction during the experiment. Lens effectivity should be taken into consideration to account for the different accommodative demand in myopes and emmetropes. Both studies (Ciuffreda and Wallis, 1998; Ciuffreda and Lee, 2002) required cognitive demand in performing the near task and measured the NITM under binocular conditions. Presence of cognitive demand and convergence-induced accommodation would affect NITM results (Wolffsohn et al., 2003b).

Rosenfield et al. (1992b) studied the effect of disparity-vergence on NITM by placing different based-in and based-out prisms while controlling accommodative demand, and showed disparity-vergence and NITM are not related to each other. Rosenfield and Ciuffreda (1994) showed NITM was similar when subjects were asked to perform near tasks with different degrees of mental effort and cognitive demand. The subjects recruited by Rosenfield and Ciuffreda were emmetropes only and the effect of cognitive effort on NITM in other refractive groups is unknown.

The results for PM, SM and emmetropes in the present study have not been compared with the literature as the number of subjects was small in each sub-group.

12.1.3. Non-Chinese adults versus Chinese adults

12.1.3.a. Results

The mean NITM in the first 10-seconds and the third 10-seconds after task removal are listed in Table 12.1.3.a.1.

	Non-Chinese adults		**Chinese adults**	
	Emmetropes (n = 17)	**Myopes (n = 18)**	**Emmetropes (n = 21)**	**Myopes (n = 22)**
	1st 10-seconds post-change			
Task A (5.0 D to 0.0 D)	0.33 ± 0.33 D**	0.27 ± 0.29 D**	0.30 ± 0.25 D**	0.31 ± 0.37 D**
Task B (2.5 D to 0.0 D)	0.34 ± 0.32 D**	0.34 ± 0.21 D**	0.28 ± 0.24 D**	0.22 ± 0.28 D**
	3rd 10-seconds post-change			
Task A (5.0 D to 0.0 D)	0.21 ± 0.27 D**	0.11 ± 0.19 D**	0.06 ± 0.20 D	0.16 ± 0.34 D**
Task B (2.5 D to 0.0 D)	0.01 ± 0.26 D	0.21 ± 0.18 D**	0.10 ± 0.19 D**	−0.01 ± 0.13 D

Table 12.1.3.a.1. The mean (± SD) NITM of non-Chinese and Chinese adults in the first 10-seconds and the third 10-seconds post-change. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

With the control of age, a three-way ANCOVA (refractive groups, stimuli and race were set as independent variables and age set as covariate) showed similar NITM at either the first 10-seconds or the third 10-seconds post-change between non-Chinese adults and Chinese adults (1st 10-seconds: $F_{(1, 147)} = 0.72$, $p > 0.05$; 3rd 10-seconds: $F_{(1,147)} = 1.50$; $p > 0.05$). Emmetropes and myopes had similar NITM in the first or third 10-seconds post-change (1st 10-seconds: $F_{(1, 147)} = 0.32$, $p > 0.05$; 3rd 10-seconds: $F_{(1,147)} = 0.52$, $p > 0.05$). There was no dose effect on NITM at different time intervals post-change (1st 10-seconds: $F_{(1, 147)} = 0.05$, $p > 0.05$; 3rd 10-seconds: $F_{(1,147)} = 2.41$, $p > 0.05$). There was no interaction between variables in the first 10-seconds post-change ($p > 0.05$), but there was a significant interaction effect between refractive groups, stimuli and race in NITM at the third 10-seconds post-change ($F_{(1,147)} = 12.12$, $p < 0.05$).

12.1.3.b. Discussion

There has been no previous study comparing NITM between different racial groups. This study did not find any significant difference in NITM between non-Chinese and Chinese adults, suggesting that NITM is unlikely to be a factor in high prevalence of myopia in Chinese adults.

12.2. Chinese children

12.2.1. Cross-sectional study

12.2.1.a. Results

The mean NITM in the first 10-seconds, the third 10-seconds, the first, second and third minutes after task removal are listed in Table 12.2.1.a.1.

	1st 10-seconds post-change	**3rd 10-seconds post-change**	**1st minute post-change**	**2nd minute post-change**	**3rd minute post-change**
			Emmetropes (n=8)		
Task A (5.0 D to 0.0 D)	0.11 ± 0.41 D	− 0.04 ± 0.22 D	− 0.01 ± 0.33 D	− 0.07 ± 0.24 D	0.01 ± 0.27 D
Task B (2.5 D to 0.0 D)	0.02 ± 0.34 D	− 0.22 ± 0.36 D	− 0.06 ± 0.19 D	− 0.07 ± 0.28 D	− 0.19 ± 0.24 D
			Myopes (n=23)		
Task A (5.0 D to 0.0 D)	0.06 ± 0.55 D	0.06 ± 0.43 D	0.06 ± 0.34 D	0.00 ± 0.31 D	− 0.05 ± 0.33 D
Task B (2.5 D to 0.0 D)	− 0.06 ± 0.38 D	−0.09 ± 0.25 D	− 0.06 ± 0.24 D	− 0.11 ± 0.28 D	− 0.11 ± 0.34 D

Table 12.2.1.a.1. The mean (± SD) NITM of Chinese children in 3-minute post-change in the cross-sectional study.

Two-way ANCOVA (with refractive groups and stimuli set as independent variables and age as covariate) did not show any significant differences in NITM in either the first 10-seconds or the third 10-seconds post-change between refractive groups (1st 10-seconds: $F_{(1,57)} = 0.46$, $p > 0.05$; 3rd 10-seconds: $F_{(1,57)} = 1.33$, $p > 0.05$) and stimuli (1st 10-seconds: $F_{(1,57)} = 0.63$, $p > 0.05$; 3rd 10-seconds: $F_{(1,57)} = 2.64$, $p > 0.05$), and no statistically significant interaction between refractive groups and stimuli (1st 10-seconds: $F_{(1,57)} = 0.02$, $p > 0.05$; 3rd 10-seconds: $F_{(1,57)} = 0.03$, $p > 0.05$).

Two-way repeated measures ANCOVA (with refractive groups and time set as independent variables and age as covariate) demonstrated similar accommodation during the first 3 minutes after the 5.0 D and 2.5 D tasks (5.0 D: $F_{(2, 56)} = 0.42$, $p > 0.05$; 2.5 D: $F_{(2, 58)} = 0.73$, $p > 0.05$). There was no significant difference between refractive groups (5.0 D: $F_{(1, 28)} = 0.03$, $p > 0.05$; 2.5 D: $F_{(1, 28)} = 0.03$, $p > 0.05$) and no significant interaction between refractive groups and time (5.0 D: $F_{(2, 56)} = 0.41$, $p > 0.05$; 2.5 D: $F_{(2, 56)} = 0.28$, $p > 0.05$).

12.2.1.b. Discussion

There have been 2 previous studies investigating NITM in children (Ciuffreda and Thunyalukul, 1999; Wolffsohn et al., 2003a). Ciuffreda and Thunyalukul (1999) used a near task with high cognitive demand under binocular conditions. Their myopes had greater NITM than emmetropes. Their child myopes experienced a more sustained NITM than adult myopes, and their NITM did not decay back to pre-task level in the first 2 minutes post-change measurement time. They suggested that this was due to lower blur sensitivity in myopes than emmetropes and different sympathetic innervation in children compared to adults. Children with recent onset of myopia who had NITM together with lag of accommodation at near were expected to exhibit cumulative retinal defocus leading to axial elongation. Myopic children who were undercorrected (by about 0.75 D and visual acuity dropped to 6/12) had greater myopia progression and axial elongation than those were fully corrected (Chung et al., 2002). Myopic defocus increased the rate of myopia progression which is contrary to the results obtained in animal studies. This indicated that myopia is caused by a malfunction of the detection system for the direction of the optical defocus on the retina rather than by a zero point error mechanism. With the development of advanced technology, Wolffsohn et al. (2003a) (including the present author) measured NITM in Chinese children using a modified Shin-Nippon SRW-5000 auto-refractor operated in a continuous mode. Their protocol was similar to that of the current study. They found similar results to that of Ciuffreda and Thunyalukul (1999), that is myopes experienced greater

NITM than emmetropes and their NITM remained longer than 3-minute post-change period.

No difference was found in NITM between myopes and emmetropes in this study. The NITM of both groups did not sustain itself throughout the first 3-minute post-change period. NITM of myopes were also lower than that reported by the previous 2 studies. Although the current protocol was similar to that by Wolffsohn et al. (2003a), the consideration of pre-change accommodative response was different. In the current study, the distant accommodative response D2 from Task C or D was treated as the reference for accommodation in the relaxed state. Wolffsohn and his co-workers calculated the NITM by subtracting the accommodative response after near task cessation with the accommodation at distance obtained from an average of 10 static readings measured through static auto-refraction. The accommodative response at distance measured by taking just 10 static readings might not reflect the true distant accommodative response, and thus the NITM readings. Subjects recruited by Ciuffreda and Thunyalukul (aged 4.7 to 9.9 years) and Wolffsohn et al. (aged 6 to 12 years) were younger than those in this study (aged 9 to 12 years). Although, Ciuffreda and Thunyalukul reported a greater NITM in myopes than emmetropes in both children and adults, it appears that the same trend of a greater NITM in myopes did not occur in an older children group.

12.2.2. Longitudinal study

12.2.2.a. Results

The mean NITM in the first 10-seconds, the third 10-seconds after task removal in Visits A, B and C are listed in Table 12.2.2.a.1., while that in the first, second and third minutes are listed in Tables 12.2.2.a.2., 12.2.2.a.3. and 12.2.2.a.4. respectively.

For NITM in the first 10-seconds post-change, three-way repeated measures ANCOVA (with visits, stimuli, refractive groups set as independent variables and age as covariate) did not show any significant difference in NTIM between visits ($F_{(2, 78)} = 0.07$, $p > 0.05$) or between refractive groups ($F_{(1, 39)} = 1.88$, $p > 0.05$). None of the interaction examinations reached a significance level of 0.05.

For NITM in the third 10-seconds post-change, three-way repeated measures ANCOVA (with visits, stimuli, refractive groups set as independent variables and age as covariate) showed no significant difference in NITM between visits ($F_{(2, 78)} = 1.62$, $p > 0.05$). Myopes had greater NITM than emmetropes for all visits ($F_{(1, 39)} = 9.29$, $p < 0.05$). NITM after the 5.0 D task was greater than that after the 2.5 D task ($F_{(1,39)} = 7.12$, $p < 0.05$). None of the interaction examinations reached a significance level of 0.05.

	Task A (5.0 D to 0.0 D)					
	1st 10-seconds post-change			**3rd 10-seconds post-change**		
	Visit A	**Visit B**	**Visit C**	**Visit A**	**Visit B**	**Visit C**
Emmetropes (n =6)	0.05 ± 0.48 D	0.12 ± 0.23 D	0.24 ± 0.20 D**	− 0.08 ± 0.25 D	0.01 ± 0.15 D	0.09 ± 0.22 D
Myopes (n =16)	0.04 ± 0.61 D	0.10 ± 0.22 D	0.30 ± 0.23 D**	0.16 ± 0.45 D	0.08 ± 0.23 D	0.17 ± 0.23 D**
	Task B (2.5 D to 0.0 D)					
	1st 10-seconds post-change			**3rd 10-seconds post-change**		
	Visit A	**Visit B**	**Visit C**	**Visit A**	**Visit B**	**Visit C**
Emmetropes (n =6)	0.02 ± 0.35 D	0.08 ± 0.15 D	0.04 ± 0.19 D	− 0.23 ± 0.42 D	− 0.04 ± 0.14 D	0.00 ± 0.22 D
Myopes (n =16)	− 0.13 ± 0.39 D	0.13 ± 0.27 D	0.20 ± 0.26 D**	− 0.11 ± 0.24 D	− 0.01 ± 0.26 D	0.02 ± 0.16 D

Table 12.2.2.a.1. The mean (± SD) NITM in the first 10-seconds and the third 10-seconds post-change of Chinese children in the longitudinal study. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

	Visit A	Visit B	Visit C
		Emmetropes (n=8)	
Task A (5.0 D to 0.0 D)	– 0.08 ± 0.36 D	0.04 ± 0.20 D	0.13 ± 0.18 D
Task B (2.5 D to 0.0 D)	– 0.08 ± 0.22 D	– 0.02 ± 0.14 D	– 0.02 ± 0.14 D
		Myopes (n=23)	
Task A (5.0 D to 0.0 D)	0.09 ± 0.40 D	0.01 ± 0.29 D	0.15 ± 0.20 D**
Task B (2.5 D to 0.0 D)	– 0.09 ± 0.27 D	0.00 ± 0.21 D	0.06 ± 0.14 D

Table 12.2.2.a.2. The mean (± SD) NITM of emmetropes and myopes in the first minute post-change in longitudinal study. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

	Visit A	Visit B	Visit C
		Emmetropes (n=8)	
Task A (5.0 D to 0.0 D)	– 0.15 ± 0.23 D	– 0.04 ± 0.26 D	0.11 ± 0.17 D
Task B (2.5 D to 0.0 D)	– 0.10 ± 0.27 D	– 0.07 ± 0.21 D	– 0.12 ± 0.19 D
		Myopes (n=23)	
Task A (5.0 D to 0.0 D)	– 0.03 ± 0.35 D	– 0.04 ± 0.28 D	0.11 ± 0.16 D**
Task B (2.5 D to 0.0 D)	– 0.14 ± 0.28 D	– 0.06 ± 0.26 D	0.01 ± 0.13 D

Table 12.2.2.a.3. The mean (± SD) NITM of emmetropes and myopes in the second minute post-change in longitudinal study. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

	Visit A	Visit B	Visit C
	Emmetropes (n=8)		
Task A (5.0 D to 0.0 D)	– 0.01 ± 0.32 D	– 0.04 ± 0.15 D	0.12 ± 0.25 D
Task B (2.5 D to 0.0 D)	– 0.19 ± 0.19 D	– 0.08 ± 0.21 D	– 0.13 ± 0.15 D
	Myopes (n=23)		
Task A (5.0 D to 0.0 D)	– 0.04 ± 0.39 D	0.00 ± 0.31 D	0.11 ± 0.20 D**
Task B (2.5 D to 0.0 D)	– 0.21 ± 0.35 D**	– 0.04 ± 0.25 D	0.04 ± 0.17 D

Table 12.2.2.a.4. The mean (± SD) NITM of emmetropes and myopes in the third minute post-change in longitudinal study. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

The first minute post-change NITM taken in Visit A (either responses after the 5.0 D or 2.5 D stimuli) were similar to those in Visit B and Visit C ($p > 0.05$). Emmetropes had similar NITM to myopes for all visits. The results for NITM in the second and third minutes post-change were the same as those in the first minute for each group.

In the current study, half of the emmetropes became myopic at the end of the longitudinal study and their NITM in the first 10-seconds and the third 10-

	Visit A	Visit B	Visit C
		Emmetropes (n=8)	
Task A (5.0 D to 0.0 D)	– 0.01 ± 0.32 D	– 0.04 ± 0.15 D	0.12 ± 0.25 D
Task B (2.5 D to 0.0 D)	– 0.19 ± 0.19 D	– 0.08 ± 0.21 D	– 0.13 ± 0.15 D
		Myopes (n=23)	
Task A (5.0 D to 0.0 D)	– 0.04 ± 0.39 D	0.00 ± 0.31 D	0.11 ± 0.20 D**
Task B (2.5 D to 0.0 D)	– 0.21 ± 0.35 D**	– 0.04 ± 0.25 D	0.04 ± 0.17 D

Table 12.2.2.a.4. The mean (± SD) NITM of emmetropes and myopes in the third minute post-change in longitudinal study. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

The first minute post-change NITM taken in Visit A (either responses after the 5.0 D or 2.5 D stimuli) were similar to those in Visit B and Visit C ($p > 0.05$). Emmetropes had similar NITM to myopes for all visits. The results for NITM in the second and third minutes post-change were the same as those in the first minute for each group.

In the current study, half of the emmetropes became myopic at the end of the longitudinal study and their NITM in the first 10-seconds and the third 10-

seconds post-change before and after onset of myopia together with the NITM from those who remained emmetropic are tabulated in Tables 12.2.2.a.5. No statistical test was done as there were only 3 subjects in each group. NITM in the first 10-seconds and the third 10-seconds post-change after the 5.0 D task are plotted in Figure 12.2.2.a.1 and similar results after the 2.5 D task are shown in Figure 12.2.2.a.2.

	Visit A		**Visit C**	
	1st 10-seconds post-change	**3rd 10-seconds post-change**	**1st 10-seconds post-change**	**3rd 10-seconds post-change**
	EMM_EMM (n = 3)		**EMM_EMM (n = 3)**	
Task A (5.0 D to 0.0 D)	− 0.26 ± 0.29 D	− 0.24 ± 0.04 D	0.14 ± 0.20 D	− 0.02 ± 0.30 D
Task B (2.5 D to 0.0 D)	− 0.15 ± 0.22 D	− 0.32 ± 0.41 D	0.02 ± 0.11 D	− 0.12 ± 0.13 D
	EMM_M (n = 3)		**EMM_M (n = 3)**	
Task A (5.0 D to 0.0 D)	0.37 ± 0.43 D	0.08 ± 0.27 D	0.35 ± 0.17 D	0.20 ± 0.04 D
Task B (2.5 D to 0.0 D)	0.19 ± 0.42 D	− 0.14 ± 0.51 D	0.06 ± 0.27 D	0.13 ± 0.23 D

Table 12.2.2.a.5. The mean (± SD) NITM of child emmetropes who remained emmetropic (EMM_EMM) and became myopic (EMM_M) in Visits A and C of the longitudinal study (i.e. before and after onset of myopia).

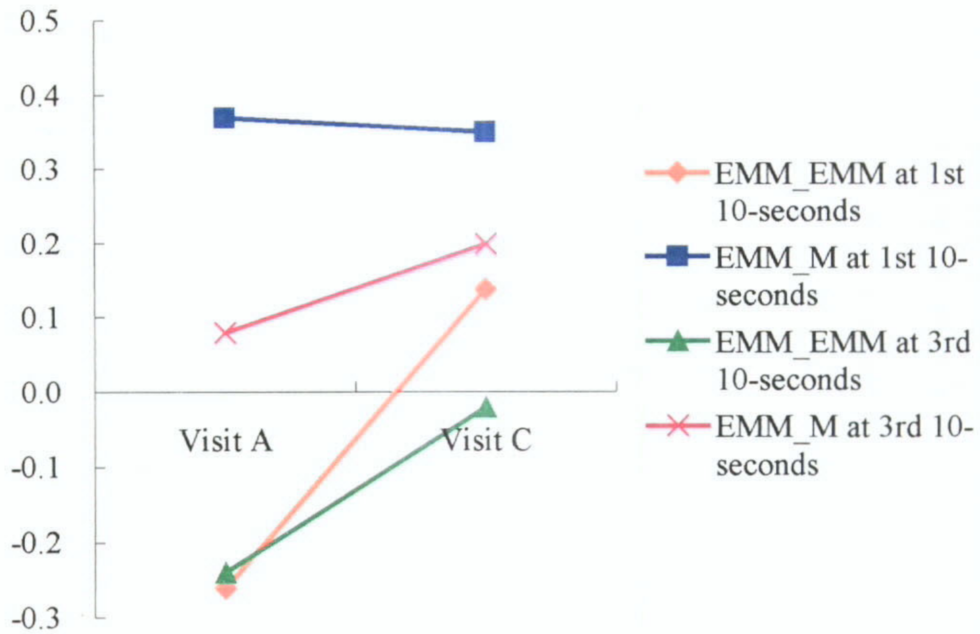

Figure 12.2.2.a.1. NITM after 5.0 D tasks of EMM_EMM and EMM_M in Visits A and C. Standard deviation was not shown for easy viewing.

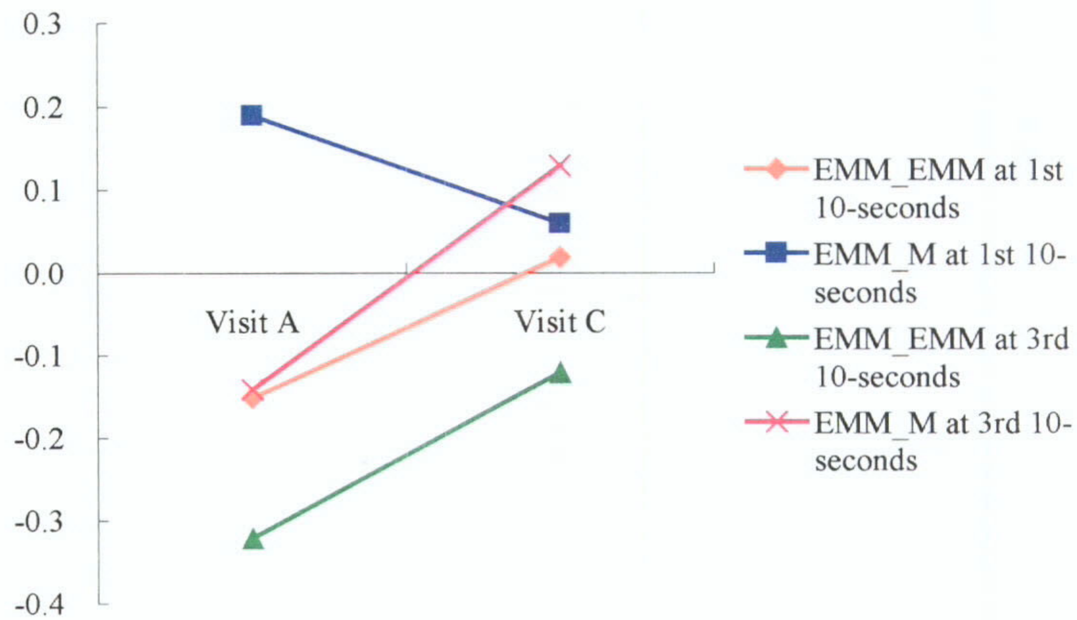

Figure 12.2.2.a.2. NITM after 2.5 D tasks of EMM_EMM and EMM_M in Visits A and C. Standard deviation was not shown for easy viewing.

12.2.2.b. Discussion

This is the first longitudinal study of NITM in Chinese children. The aim was to investigate whether NITM has a role in the development of myopia in Hong Kong Chinese children. There were no differences in NITM after the 5.0 D or 2.5 D nearwork tasks between visits. However, there was a trend of increasing NITM over the study period (Table 12.2.2.a.1.). Myopes seem to have a greater increase in NITM than emmetropes in the first 10-seconds post-change (Table 12.2.2.a.1.). Because of large inter-subject variation of NITM especially in Visit A, no significant results between visits were found for both refractive groups. This large inter-subject variation might be due to poor attention in children so that good fixation was not maintained at all times. Probably their performance improved in the sequent visits. For NITM in the third 10-seconds post-change, myopes had greater NITM than emmetropes. This showed emmetropes had a faster NITM decay than myopes.

Armstrong et al. (2000) suggested a simple method to estimate the sample size required in an experiment to have a good probability to detect a difference between 2 treatments. It is similar to an equation proposed by Rigeman (1975), in which the percentage difference detectable in an experiment and the coefficient of variation of the variables should be known Armstrong and his associates indicated that for multiple comparisons (like 2-way ANOVA), the consideration of the number of degrees of freedom of the error term would be a better way to determine an adequate sample size (Armstrong et al., 2002). The minimum emmetropes required in the current study would be 6 in terms of at least 15 degrees of freedom in the statistical results. The drop out rate of emmetropes was 25 % (8 emmetropes at visit A and 6 at visit C). Therefore, the estimated number of emmetropes in each group is 8 initially (8 EMM_EMM and 8 EMM_M).

No difference between refractive groups was found when comparing NITM between the first and second minutes, or between the second and third minutes post-change after either 5.0 D or 2.5 D nearwork tasks across all visits. Their NITM appeared to have an increase across visits, even though the degree of change in NITM across visits was not statistically significant.

The re-grouping of emmetropes into those "becoming myopic" (EMM_M) and "remaining emmetropic" (EMM_EMM) examined whether difference in NITM could be a precursor to the development of myopia. Three emmetropes became myopic (EMM_M) and 3 remained emmetropic (EMM_EMM) over the 1-year study period. Referring to Figures 12.2.2.1 and 12.2.2.2, there was an increase in NITM for both groups from Visits A to C except in EMM_M after the 2.5 D task in the first 10-seconds post-change. The NITM of EMM_M was consistently greater than that of EMM_EMM (0.18 D to 0.63 D). Ideally more emmetropes should be recruited for future work.

12.3. Chinese adults versus children

12.3.1. Results

NITM in the first 10-seconds and the third 10-seconds post-change after the 5.0 D and the 2.5 D tasks of Chinese adults and children are listed in Table 12.3.1.1.

	Adults	**Children**
	1st 10-seconds post-change	
Task A (5.0 D to 0.0 D)	0.31 ± 0.31 D	0.08 ± 0.51 D
Task B (2.5 D to 0.0 D)	0.25 ± 0.26 D	– 0.04 ± 0.37 D
	3rd 10-seconds post-change	
Task A (5.0 D to 0.0 D)	0.11 ± 0.28 D	0.03 ± 0.38 D
Task B (2.5 D to 0.0 D)	0.04 ± 0.17 D	–0.12 ± 0.28 D

Table 12.3.1.1. Then mean (± SD) NITM in the first 10-seconds and the third 10-seconds post-change of Chinese adults and children in the cross-sectional study.

Since there was no significant difference in NITM between emmetropes and myopes in either adults or children, NITM of refractive groups were combined in each age group. For NITM in the first 10-seconds post-change after either the 5.0 D or the 2.5 D tasks, unpaired t-test with Welch correction showed that adults had greater NITM than children (5D: $t = 2.22$, $df = 45$, $p < 0.05$; 2.5 D: $t = 3.75$, $df = 50$, $p < 0.001$). For NITM in the third 10-seconds post-change after the 5.0 D task, both age groups had similar NITM (Unpaired t-test with Welch correction, $t = 0.99$, $df = 52$, $p > 0.05$). For NITM in the third 10-seconds post-change after the 2.5 D task, adults had greater NITM than children (Unpaired t-test with Welch correction, $t = 2.87$, $df = 45$, $p < 0.05$).

12.3.2. Discussion

Adults demonstrated greater NITM than children in the majority of the study findings, and they had a similar lag of accommodation compared to children during near fixation (Two-way ANOVA, $p > 0.05$). Sympathetic innervation thought to be mainly responsible for reduction in accommodation, though its action depends on the concurrent level of background parasympathetic activity (Tornqvist, 1967; Gilmartin and Bullimore, 1987). The above results indicated that adults may have weaker sympathetic inhibition, resulting in a greater amount of NITM after prolonged near task cessation.

12.4. Summary

1. There were no statistically significant differences in NITM between myopes and emmetropes in both non-Chinese and Chinese adults.

2. NITM in the first minute post-change was significantly greater than that at the second- and third-minute in both non-Chinese and Chinese adults. Both emmetropes and myopes had similar NITM during the first three minutes post-change.

3. Non-Chinese adults had similar NITM as Chinese adults.

4. In the cross-sectional study, Chinese myopic and emmetropic children had similar NITM, which decayed back to baseline at a similar speed.

5. In the longitudinal study, Chinese children did not show any significant change in NITM across visits.

6. Chinese adults in general had greater NITM than children.

Chapter 13. Effect of contact lens

Effect of contact lens on the accommodative responses was investigated by repeating Task A on 8 Hong Kong Chinese adult emmetropes (out of 21 subjects from Section 8.1.2., Chapter 8).

13.1. Results

The accommodative responses are shown in Table 13.1.1. There was no statistically significant difference in near responses with and without contact lens wearing (Paired t-test, $t = 0.012$, $df = 7$, $p > 0.05$). The difference in the far responses was also not significant (Paired t-test, $t = 1.72$, $df = 7$, $p > 0.05$).

	With contact lens	**Without contact lens**
Near	3.64 ± 0.28 D	3.64 ± 0.46 D
Far	0.03 ± 0.09 D	0.08 ± 0.08 D

Table 13.1.1. The mean (± SD) accommodative responses at near and far in Task A with and without contact lens wearing.

13.2. Summary

Accommodative responses were not affected by the use of contact lens. Therefore, the use of contact lens correction in the present study was valid and should not affect the NITM measurement, and other accommodative responses.

Part IV. Conclusions and suggestions for future research

Chapter 14. Conclusions

This experiment investigated the association between nearwork and myopia, if any, through the study of various accommodative functions, namely amplitude of accommodation, the accommodative stimulus-response curve, tonic accommodation and NITM. Previous investigations of accommodative functions have been limited to non-Chinese population and whether the same results would be obtained in and therefore appropriate to Chinese, who have a high prevalence of myopia, were unknown. In this work, direct comparison of these functions, measured with the use of a more advanced instrument able to make continuous measurement of accommodative responses, were conducted between Chinese and non-Chinese using the same protocol by the same examiner. In addition, the relationship between the change in refractive error and change in the accommodative function in Chinese children was explored in a longitudinal study.

Chinese and non-Chinese adults were found to have similar amplitude of accommodation, tonic accommodation, accommodative response gradient and NITM, regardless of their refractive conditions. These findings indicate that the above accommodative functions are unlikely to be factors in the high prevalence of myopia found in Chinese. ***Chinese adults had lower accommodative amplitude, steeper gradient, higher tonic accommodation and NITM than Chinese children. There was no statistically significant change in accommodative amplitude, gradient or the NITM in the children followed for one year. Chinese myopic children showed an increase in tonic accommodation in the longitudinal study and it was not related to the change in ocular refraction. There was no significant difference in amplitude of accommodation, tonic accommodation, gradient or NITM between myopic and emmetropic subjects, except that child emmetropes had greater accommodative amplitude than myopes.*** Based on the present findings, the notion that accommodation plays a role in the development and progression of myopia is still unproven.

Current study had several limitations, namely:

1. The relatively small subject numbers along with large inter-subject variation in the studies involving children, may be why the majority of the results did not show a statistically significant difference in accommodative function between refractive groups. These happened especially in the tonic accommodation experiment.

2. In the amplitude of accommodation experiment, the angular size of the target was not controlled. When the target approached the subject's eye, the target size would appear larger. This would produce a delay in appreciating the presence of blur, leading to an increase in the amplitude of accommodation measured. Further, as the dioptric scale in the RAF rule is non-linear, judgment of accommodative reading could vary in accuracy with the amplitude of accommodation of the individual. The same interval measured in centimetre along the RAF ruler will result in different dioptric differences.

3. In the study of the accommodative stimulus-response curve, the stimulus range (0.17 D to 5 D) was not wide enough to cover up to the amplitude of accommodation. Decreasing distance method was used and the closest distance that the target could be placed in front of the Shin-Nippon SRW 5000 auto-refractor was 20 cm.

4. In the tonic accommodation experiment, a faint red ring was seen in the centre of the Shin-Nippon SRW-5000 auto-refractor. This may distract a child's attention from the DOG target during measurement.

5. In the NITM experiment, the subject had his or her chin positioned on the instrument chin-rest throughout the experiment. Although every effort was made to make this position comfortable, it is possible that the subject could become fatigued. In addition, a letter target was used as an accommodative stimulus and this might not be an ideal fixation target for children, because the target was not sufficiently interesting and the duration of this experiment was long. The experiment can be modified to arouse the interest of children. For example, using a picture target or displaying the target using a LCD (Liquid Crystal Display) monitor

allowing the sequential presentation of words (allowing the child to read a story during each task).

Chapter 15. Suggestions for future research

1. More subjects should be recruited in adult myopic sub-groups and child emmetropes. Nine out of 31 children (29 %) in the longitudinal study dropped out after their first visit. The reason for this was because of long experimental duration where subjects would find it difficult in maintaining fixation during the NITM experiment. In order to study the change in accommodative responses before and after the onset of myopia, a greater number of emmetropic children should be recruited to maintain significant number for statistical data analysis. For example, EMM_M showed consistently greater NITM in the first 10-seconds and third 10-seconds post-task than EMM_EMM (0.18 D to 0.63 D) throughout the longitudinal study. Due to small subject number in each group (n = 3), no statistical test could be performed.

2. Children should be followed for at least 2 years to allow greater degree of myopia progression. However, the long experimental time makes subject recruitment and retention more difficult.

3. Accommodative stimulus-response curve should be plotted using a polynomial equation. With the derivation of the equation, the gradient could be found with the non-linear region taken into consideration. This method should be adopted in any further study on accommodative stimulus-response curve.

4. Calculation of the time constants of NITM decay, which can determine more precisely the time at which the subject's NITM decayed to baseline values, is suggested. This time constant can make comparison with current literature easier and provides a more complete picture of NITM.

Appendix I. Additional results for NITM experiment

Nearwork-induced transient myopia of different refractive groups had been reported in Chapter 12 and other accommodative responses during each task were reported in this appendix. Those recorded in the first 5 minutes (0 to 300 seconds) of measurement of each task were called "pre-change". Responses recorded during the following 3 minutes (i.e. from 301 to 480 seconds) were termed "post-change". As mentioned previously in Section 7.4.4. (Chapter 7), the responses obtained from the first 5 minutes (from 0 to 300 seconds after commencement of task) in tasks A and B (near to far section) were termed active accommodation A1 ($A1_A$ for Task A and $A1_B$ for Task B). For tasks C and D (far to near section), readings during the 5-minute (from 0 to 300 seconds) distant fixation represented baseline distance accommodation D2 ($D2_C$ for Task C and $D2_D$ for Task D) and the rest (from 301 to 480 seconds) showed active accommodation A2 ($A2_C$ for Task C and $A2_D$ for Task D) for near viewing.

Unless specified, two-way ANOVA tests, with refractive groups (emmetropes and myopes) and stimuli (5.0 D and 2.5 D) set as independent variables were performed to investigate the effect of refractive groups and the use of different stimuli on accommodative responses, and any possible interaction between these two factors.

A1.1. Adults

A1.1.1. Non-Chinese adults

Accommodative responses in Task A to Task D of emmetropes and myopes are shown in Table A1.1.1.1, while that of myopic sub-groups are listed in Table A1.1.1.2.

	Emmetropes (n = 17)	**Myopes (n= 18)**
	Pre-change	
Task A (5.0 D to 0.0 D)	$A1_A$, 4.05 ± 0.38 D	$A1_A$, 3.89 ± 0.34 D
Task B (2.5 D to 0.0 D)	$A1_B$, 1.97 ± 0.40 D	$A1_B$, 2.01 ± 0.40 D
Task C (0.0 D to 5.0 D)	$D2_C$, – 0.06 ± 0.14 D	$D2_C$, 0.02 ± 0.12 D
Task D (0.0 D to 2.5 D)	$D2_D$, – 0.04 ± 0.17 D	$D2_D$, – 0.02 ± 0.12 D
	Post-change	
Task C (0.0 D to 5.0 D)	$A2_C$, 3.98 ± 0.38 D	$A2_C$, 3.95 ± 0.42 D
Task D (0.0 D to 2.5 D)	$A2_D$, 1.99 ± 0.37 D	$A2_D$, 1.97 ± 0.42 D

Table A1.1.1.1. Mean (± SD) accommodative responses of non-Chinese emmetropes and myopes.

	LOM (n = 4)	**EOM (n =14)**	**PM (n = 10)**	**SM (n = 8)**
	Pre-change			
Task A (5.0 D to 0.0 D)	$A1_A$, 4.13 ± 0.25 D	$A1_A$, 3.82 ± 0.34 D	$A1_A$, 4.06 ± 0.30 D	$A1_A$, 3.69 ± 0.29 D
Task B (2.5 D to 0.0 D)	$A1_B$, 2.48 ± 0.24 D	$A1_B$, 1.88 ± 0.34 D	$A1_B$, 2.15 ± 0.32 D	$A1_B$, 1.84 ± 0.45 D
Task C (0.0 D to 5.0 D)	$D2_C$, − 0.08 ± 0.10 D	$D2_C$, 0.05 ± 0.11 D	$D2_C$, 0.01 ± 0.13 D	$D2_C$, 0.03 ± 0.12 D
Task D (0.0 D to 2.5 D)	$D2_D$, − 0.10 ± 0.08 D	$D2_D$, 0.00 ± 0.12 D	$D2_D$, − 0.05 ± 0.14 D	$D2_D$, 0.00 ± 0.09 D
	Post-change			
Task C (0.0 D to 5.0 D)	$A2_C$, 4.22 ± 0.50 D	$A2_C$, 3.87 ± 0.38 D	$A2_C$, 4.09 ± 0.39 D	$A2_C$, 3.78 ± 0.41 D
Task D (0.0 D to 2.5 D)	$A2_D$, 2.49 ± 0.27 D	$A2_D$, 1.82 ± 0.33 D	$A2_D$, 2.05 ± 0.43 D	$A2_D$, 1.88 ± 0.43 D

Table A1.1.1.2. Mean (± SD) accommodative responses of non-Chinese myopic sub-groups. LOM: Late-onset myopes; EOM: Early-onset myopes; PM: Progressing myopes; SM: Stable myopes.

(i) Near to far (Tasks A and B)

Near

Two-way ANOVA showed that the near responses for 5.0 D were significantly higher than those for 2.5 D ($F_{(1,66)} = 470.40$, $p < 0.001$). There was no significant difference between refractive groups ($F_{(1, 66)} = 0.42$, $p > 0.05$) and no interaction effect between refractive groups and stimuli ($F_{(1,66)} = 1.21$, $p > 0.05$).

(ii) Far to near (Tasks C and D)

Far

There were no significant differences in accommodative response between refractive groups ($F_{(1,66)} = 1.94$, $p > 0.05$) or stimuli ($F_{(1,66)} = 0.15$, $p > 0.05$), and no significant interaction between refractive groups and stimuli ($F_{(1,66)} = 0.92$, $p > 0.05$).

Near

The near responses for 5.0 D were significantly higher than that for 2.5 D (Two-way ANOVA: $F_{(1,66)} = 437.00$, $p < 0.001$). There was no significant difference in the near responses between refractive groups ($F_{(1,66)} = 0.07$, $p > 0.05$) and no interaction effect between refractive groups and stimuli ($F_{(1,66)} = 0.01$, $p > 0.05$).

A1.1.2. Chinese adults

Accommodative responses in Task A to Task D of emmetropes and myopes are listed in Table A1.1.2.1, while that of myopic sub-groups are shown in Table A1.1.2.2.

	Emmetropes (n = 21)	**Myopes (n= 22)**
	Pre-change	
Task A (5.0 D to 0.0 D)	$A1_A$, 3.64 ± 0.31 D	$A1_A$, 3.89 ± 0.42 D
Task B (2.5 D to 0.0 D)	$A1_B$, 1.70 ± 0.34 D	$A1_B$, 1.86 ± 0.35 D
Task C (0.0 D to 5.0 D)	$D2_C$, 0.04 ± 0.11 D	$D2_C$, 0.06 ± 0.14 D
Task D (0.0 D to 2.5 D)	$D2_D$, 0.03 ± 0.15 D	$D2_D$, 0.02 ± 0.12 D
	Post-change	
Task C (0.0 D to 5.0 D)	$A2_C$, 3.70 ± 0.35 D	$A2_C$, 3.89 ± 0.38 D
Task D (0.0 D to 2.5 D)	$A2_D$, 1.80 ± 0.34 D	$A2_D$, 1.89 ± 0.36 D

Table A1.1.2.1. Mean (± SD) accommodative responses of Chinese emmetropes and myopes.

	LOM (n = 9)	EOM (n =13)	PM (n = 5)	SM (n = 17)
	Pre-change			
Task A (5.0 D to 0.0 D)	$A1_A$, 3.94 ± 0.48 D	$A1_A$, 3.86 ± 0.39 D	$A1_A$, 3.95 ± 0.40 D	$A1_A$, 3.88 ± 0.43 D
Task B (2.5 D to 0.0 D)	$A1_B$, 1.73 ± 0.37 D	$A1_B$, 1.95 ± 0.31 D	$A1_B$, 1.94 ± 0.37 D	$A1_B$, 1.84 ± 0.35 D
Task C (0.0 D to 5.0 D)	$D2_C$, 0.04 ± 0.14 D	$D2_C$, 0.07 ± 0.15 D	$D2_C$, − 0.01 ± 0.17 D	$D2_C$, 0.08 ± 0.13 D
Task D (0.0 D to 2.5 D)	$D2_D$, 0.00 ± 0.11 D	$D2_D$, 0.04 ± 0.14 D	$D2_D$, − 0.11 ± 0.10 D	$D2_D$, 0.06 ± 0.10 D
	Post-change			
Task C (0.0 D to 5.0 D)	$A2_C$, 3.98 ± 0.38 D	$A2_C$, 3.83 ± 0.38 D	$A2_C$, 3.83 ± 0.39 D	$A2_C$, 3.91 ± 0.39 D
Task D (0.0 D to 2.5 D)	$A2_D$, 1.78 ± 0.31 D	$A2_D$, 1.97 ± 0.38 D	$A2_D$, 1.94 ± 0.26 D	$A2_D$, 1.88 ± 0.39 D

Table A1.1.2.2. Mean (± SD) accommodative responses of Chinese myopic sub-groups. LOM: Late-onset myopes; EOM: Early-onset myopes; PM: Progressing myopes; SM: Stable myopes.

(i) Near to far (Tasks A and B)

Near

Near responses of myopes were significantly higher than those of emmetropes ($F_{(1, 82)} = 7.61$, $p < 0.05$). Near responses for 5.0 D were significantly higher than those for 2.5 D in both refractive groups ($F_{(1,82)} = 665.31$, $p < 0.001$). There was no interaction effect between refractive groups and stimuli ($F_{(1, 82)} = 0.33$, $p > 0.05$).

(ii) Far to near (Tasks C and D)

Far

There were no significant differences in accommodative response between refractive groups ($F_{(1,82)} = 0.07$, $p > 0.05$) or between stimuli ($F_{(1,82)} = 0.58$, $p > 0.05$), and no significant interaction between refractive groups and stimuli ($F_{(1,82)} = 0.25$, $p > 0.05$).

Near

The near response for 5.0 D was significantly higher than that for 2.5 D (Two-way ANOVA: $F_{(1,82)} = 633.11$, $p < 0.001$). There was no statistically significant difference between refractive groups ($F_{(1,82)} = 3.31$, $p > 0.05$) and no interaction effect between refractive groups and stimuli ($F_{(1,82)} = 0.47$, $p > 0.05$).

A1.1.3. Non-Chinese adults versus Chinese adults

(i) Near to far

Near

Three-way ANCOVA (refractive groups, stimuli and race were set as independent variables and age as covariate) demonstrated that near accommodative responses of non-Chinese adults were higher than that of Chinese adults ($F_{(1, 147)} = 8.77$, $p < 0.05$). As expected, responses at 5.0 D were higher than those at 2.5 D ($F_{(1, 147)} = 1118.85$, $p < 0.001$). Only the interaction effect between refractive groups and race reached 5 % significance level ($F_{(1, 147)} = 5.52$, $p < 0.05$). The difference in near responses between racial groups was more prominent in emmetropes than in myopes (Figure A1.1.3.1.) and the difference in near responses between refractive groups was greater in Chinese than in non-Chinese adults (Figure A1.1.3.2.).

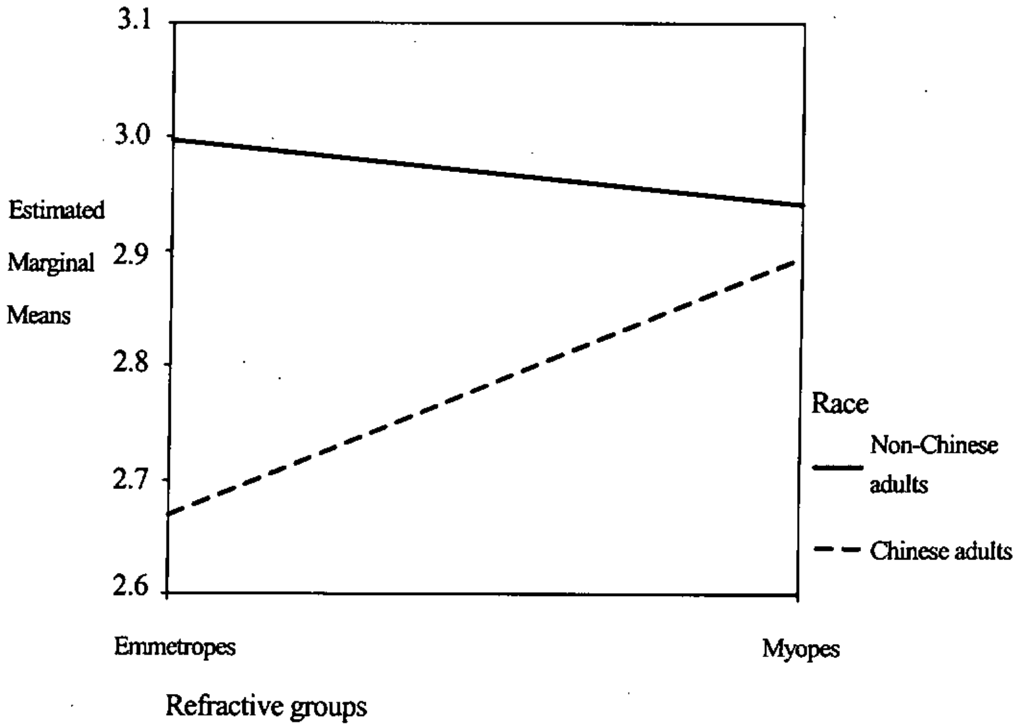

Figure A1.1.3.1. Interaction plot with race against refractive groups.

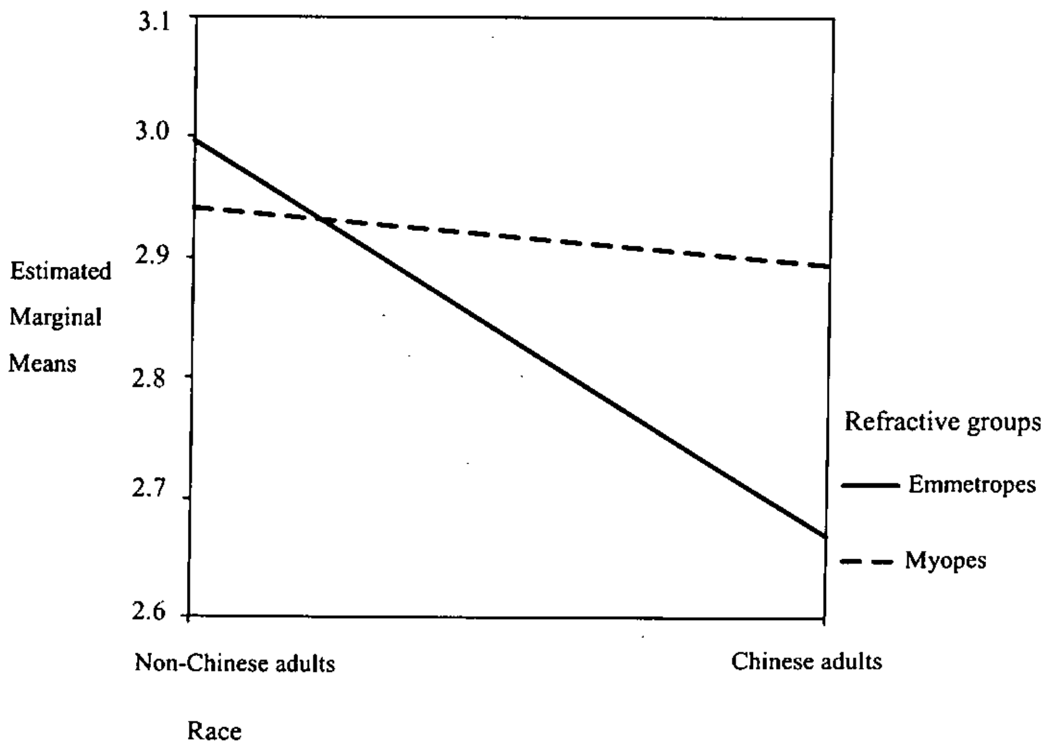

Figure A1.1.3.2. Interaction plot with refractive groups against race.

(i) Far to near

Far

Chinese adults had a greater lead of accommodation than non-Chinese adults (3-way ANCOVA (refractive groups, stimuli and race were set as independent variables and age as covariate): $F_{(1, 147)} = 5.52$, $p < 0.05$). There were no significant differences between refractive groups ($F_{(1, 147)} = 1.23$, $p > 0.05$) or between stimuli ($F_{(1, 147)} = 0.65$, $p > 0.05$). None of the interaction effect reached a significance level of 5%.

Near

Three-way ANCOVA (refractive groups, stimuli and race were set as independent variables and age as covariate) did not demonstrate near accommodative responses of non-Chinese adults were greater than those of Chinese adults ($F_{(1, 147)} = 3.75$, $p > 0.05$). As expected, responses at 5.0 D were higher than that at 2.5 D ($F_{(1, 147)} = 1054.95$, $p < 0.001$). There was no significant difference between refractive groups ($F_{(1, 147)} = 1.22$, $p > 0.05$) and none of the interaction effect reached 5 % significance level.

A1.2. Children

A1.2.1. Cross-sectional study

Accommodative responses in Task A to Task D are listed in Table A1.2.1.1.

	Emmetropes (n = 8)	**Myopes (n= 23)**
	Pre-change	
Task A (5.0 D to 0.0 D)	$A1_A$, 3.89 ± 0.56 D	$A1_A$, 4.13 ± 0.65 D
Task B (2.5 D to 0.0 D)	$A1_B$, 1.65 ± 0.30 D	$A1_B$, 1.76 ± 0.45 D
Task C (0.0 D to 5.0 D)	$D2_C$, – 0.02 ± 0.05 D	$D2_C$, – 0.04 ± 0.35 D
Task D (0.0 D to 2.5 D)	$D2_D$, 0.02 ± 0.13 D	$D2_D$, 0.07 ± 0.21 D
	Post-change	
Task C (0.0 D to 5.0 D)	$A2_C$, 3.95 ± 0.52D	$A2_C$, 4.08 ± 0.66 D
Task D (0.0 D to 2.5 D)	$A2_D$, 1.69 ± 0.27 D	$A2_D$, 1.70 ± 0.30 D

Table A1.2.1.1. Mean (± SD) accommodative responses of child emmetropes and myopes at the first visit.

(i) Near to far (Tasks A and B)

Near

Near response of myopes were greater than that of emmetropes (Two-way ANCOVA, $F_{(1,57)} = 4.25$, $p < 0.05$). Near responses for 5.0 D were significantly higher than those for 2.5 D in both refractive groups ($F_{(1,57)} = 239.37$, $p < 0.001$). There was no significant interaction between refractive groups and stimuli ($F_{(1,57)} = 0.19$, $p > 0.05$).

(ii) Far to near (Tasks C and D)

Far

There was no significant difference in accommodative responses between refractive groups at either 5.0 D (Unpaired t-test with Welch correction, $t = 0.30$, $df = 24$, $p > 0.05$) or 2.5 D tasks (Unpaired t-test, $t = 0.69$, $df = 29$, $p > 0.05$).

Near

Near responses for 5.0 D were not significantly higher than those for 2.5 D (Two-way ANCOVA: $F_{(1,57)} = 1.41$, $p > 0.05$). The accommodative responses were similar between refractive groups ($F_{(1,57)} = 0.06$, $p > 0.05$) and there was no interaction effect between refractive groups and stimuli ($F_{(1,57)} = 0.01$, $p > 0.05$).

A1.2.2. Longitudinal study

The pre-change and post-change accommodative responses for all visits are shown in Tables A1.2.2.1. and A1.2.2.2. respectively.

Pre-change	**Visit A**	**Visit B**	**Visit C**
	Emmetropes (n = 6)		
Task A (5.0 D to 0.0 D)	$A1_A$, 3.98 ± 0.63 D	$A1_A$, 3.49 ± 0.30 D	$A1_A$, 3.68 ± 0.17 D
Task B (2.5 D to 0.0 D)	$A1_B$, 1.68 ± 0.33 D	$A1_B$, 1.63 ± 0.31 D	$A1_B$, 1.66 ± 0.23 D
Task C (0.0 D to 5.0 D)	$D2_C$, – 0.03 ± 0.04 D	$D2_C$, 0.01 ± 0.10 D	$D2_C$, – 0.02 ± 0.23 D
Task D (0.0 D to 2.5 D)	$D2_D$, 0.03 ± 0.15 D	$D2_D$, – 0.02 ± 0.09 D	$D2_D$, 0.04 ± 0.09 D
	Myopes (n= 16)		
Task A (5.0.0 D to 0 D)	$A1_A$, 4.04 ± 0.50 D	$A1_A$, 3.54 ± 0.22 D	$A1_A$, 3.79 ± 0.19 D
Task B (2.5 D to 0.0 D)	$A1_B$, 1.68 ± 0.34 D	$A1_B$, 1.65 ± 0.38 D	$A1_B$, 1.73 ± 0.29 D
Task C (0.0 D to 5.0 D)	$D2_C$, – 0.01 ± 0.39 D	$D2_C$, 0.01 ± 0.19 D	$D2_C$, 0.00 ± 0.08 D
Task D (0.0 D to 2.5 D)	$D2_D$, 0.13 ± 0.20 D	$D2_D$, 0.01 ± 0.21D	$D2_D$, 0.03 ± 0.10 D

Table A1.2.2.1. Mean (± SD) pre-change accommodative responses of child emmetropes and myopes in Visits A, B and C.

Post-change	Visit A	Visit B	Visit C
	Emmetropes (n = 6)		
Task C (0.0 D to 5.0 D)	$A2_C$, 4.10 ± 0.52 D	$A2_C$, 3.53 ± 0.37 D	$A2_C$, 3.68 ± 0.29 D
Task D (0.0 D to 2.5 D)	$A2_D$, 1.69 ± 0.29 D	$A2_D$, 1.49 ± 0.38 D	$A2_D$, 1.74 ± 0.23 D
	Myopes (n= 16)		
Task C (0.0 D to 5.0 D)	$A2_C$, 3.96 ± 0.60 D	$A2_C$, 3.62 ± 0.23 D	$A2_C$, 3.80 ± 0.19 D
Task D (0.0 D to 2.5 D)	$A2_D$, 1.68 ± 0.35 D	$A2_D$, 1.62 ± 0.39 D	$A2_D$, 1.79 ± 0.29 D

Table A1.2.2.2. Mean (± SD) post-change accommodative responses of child emmetropes and myopes in Visits A, B and C.

A1.3. Chinese adults versus children

Accommodative responses of Chinese adults and children in the cross-sectional study were compared and the results are presented below.

(i) Near to far

Near

The accommodative responses at 5.0 D and 2.5 D were similar in adults and children (Two-way ANOVA, $p > 0.05$). .

(ii) Far to near

Far

There was no significant difference in accommodation in Tasks C and D in adults and children (Two-way ANOVA, $p > 0.05$).

Near

Both adults and children demonstrated similar amount of near accommodation in Tasks C and D (Two-way ANOVA, $p > 0.05$).

Appendix II. Information sheet

Appendix II A.2.1.

Information Sheet for non-Chinese adult study

Department of Vision Sciences

Aston University

Department of Optometry and Radiography

The Hong Kong Polytechnic University

Dynamics of accommodation study

Information sheet

This work is to investigate the way the eye responds to a near image, in particular the way the eye focusses or "accommodates" to make a near image clear. It is believed that there is a link between myopia (short-sight) and near work, this has led to the notion that accommodation plays a role in the development and progression of myopia. This is a collaborative study carried out jointly by Aston University and The Hong Kong Polytechnic University (PolyU). The Hong Kong researcher, Miss Bibianna Yu, is an MPhil student of the Department of Optometry and Radiography, The PolyU. She will carry out the measurements under the supervision of Dr. James Wolffsohn, Aston University.

A routine eye examination to assess your vision and eye health will be carried out in the Optometry clinic. If you have a refractive error you will be asked to wear a disposable soft contact lens during the measurement. There is a low risk that the insertion or removal of the lens could cause some minor discomfort.

After inserting the contact lens, we will ask you to sit in front of an autorefractor and look at words presented at different distances. A continuous automatic measurement of refractive error will be taken. Contact lens will be removed immediately after the experiment and we will check the health of your cornea again before you leave the clinic.

The whole procedures will take about one and a half hours and neither invasive tests nor eye drops will be used.

You will be asked to sign an informed consent form that states you understand the information presented on this sheet. All data collected will be kept confidential and only be used for the purpose of this study. You will not be identifiable in any publication describing this research. You have every right to withdrawn from the study before or during the measurement without penalty of any kind.

Miss Bibianna Yu and Dr James Wolffsohn will be pleased to answer any questions about the project you may have (Telephone: 0121 359 3611 ext 5160). If you have any comments or complaints about the conduct of the study, please address them to the Chairman, Aston University Ethics Committee.

Thank you for your interest in participating in this study

Appendix II A.2.2.

Information Sheet for Chinese adult study

Department of Optometry and Radiography

The Hong Kong Polytechnic University

Dynamics of accommodation study

Information sheet

This work is to investigate the way the eye responds to a near image, in particular the way the eye focusses or "accommodates" to make a near image clear. It is believed that there is a link between myopia (short-sight) and near work, this has led to the notion that accommodation plays a role in the development and progression of myopia.

A routine eye examination to assess your vision and eye health will be carried out in the Optometry clinic. If you have a refractive error you will be asked to wear a disposable soft contact lens during the measurement. There is a low risk that the insertion or removal of the lens could cause some minor discomfort.

After inserting the contact lens, we will ask you to sit in front of an autorefractor and look at words presented at different distances. A continuous automatic measurement of refractive error will be taken. Contact lens will be removed immediately after the experiment and we will check the health of your cornea again before you leave the clinic.

The whole procedures will take about one and a half hours and neither invasive tests nor eye drops will be used.

You will be asked to sign an informed consent form that states you understand the information presented on this sheet. All data collected will be kept confidential and only be used for the purpose of this study. You will not be identifiable in any publication describing this research. You have every right to withdrawn from the study before or during the measurement without penalty of any kind.

Miss Bibianna Yu will be pleased to answer any questions about the project you may have (Telephone: 2766 4003). If you have any comments or complaints about the conduct of the study, please address them to the Secretary, Human Subjects Ethics Sub-committee, The Hong Kong Polytechnic University.

Thank you for your interest in participating in this study

Appendix II A.2.3.

Information Sheet for Chinese children study

Department of Optometry and Radiography

The Hong Kong Polytechnic University

Dynamics of accommodation study

Information sheet

This work is to investigate the way the eye responds to a near image, in particular the way the eye focusses or "accommodates" to make a near image clear. It is believed that there is a link between myopia (short-sight) and near work, this has led to the notion that accommodation plays a role in the development and progression of myopia.

Your child will be asked to come back 4 times at 4-month intervals in a year to participate this study. A routine eye examination to assess your vision and eye health will be carried out in the Optometry clinic. If your child has a refractive error he/ she will be asked to wear a disposable soft contact lens during the measurement. There is a low risk that the insertion or removal of the lens could cause some minor discomfort.

After inserting the contact lens, we will ask he/ she to sit in front of an autorefractor and look at words presented at different distances. A continuous automatic measurement of refractive error will be taken. Contact lens will be removed immediately after the experiment and we will check the health of your child's cornea again before he/ she leave the clinic.

The whole procedures will take about one and a half hours and neither invasive tests nor eye drops will be used.

You will be asked to sign an informed consent form that states you understand the information presented on this sheet. All data collected will be kept confidential and only be used for the purpose of this study. You and your child will not be identifiable in any publication describing this research. Your child has every right to withdrawn from the study before or during the measurement without penalty of any kind.

Miss Bibianna Yu will be pleased to answer any questions about the project you may have (Telephone: 2766 4003). If you have any comments or complaints about the conduct of the study, please address them to the Secretary, Human Subjects Ethics Sub-committee, The Hong Kong Polytechnic University.

Thank you for your interest in participating in this study

Appendix III. Consent form

A3.1. Consent form for adult subjects

Dynamics of accommodation study

Consent form

Yes/ No

Have you read the information sheet provided?

Yes/ No

Have you had an opportunity to ask questions and discuss this study?

Yes/ No

Have you received satisfactory answers to all of your questions?

Yes/ No

Have you received enough information about the study?

Who provided the information/ answered your questions

Ms/ Mr/ Dr/ Prof ______________________________

Yes/ No

Do you understand that participation is entirely voluntary?

Do you understand that you are free to withdraw from the study Yes/ No

- at any time

Yes/ No

- without having to give a reason

Yes/ No

- without affecting your future care in the Optometry Clinic

Yes/ No

Do you agree to take part in this study

Signature of subject: ______________________________

Name of subject: ______________________________

Date: ______________________________

Appendix III A.3.2.

Consent form for children subjects

Dynamics of accommodation study

Parent consent form

Have you read the information sheet provided?	Yes/ No
Have you had an opportunity to ask questions and discuss this study?	Yes/ No
Have you received satisfactory answers to all of your questions?	Yes/ No
Have you received enough information about the study?	Yes/ No

Who provided the information/ answered your questions
Ms/ Mr/ Dr/ Prof ____________________

Do you understand that participation is entirely voluntary?	Yes/ No

Do you understand that you are free to withdraw from the study

❑ at any time	Yes/ No
❑ without having to give a reason	Yes/ No
❑ without affecting your future care in the Optometry Clinic	Yes/ No

Do you agree to take part in this study	Yes/ No

Name of child: ____________________

Name of parent: ____________________

Signature of parent: ____________________

Date: ____________________

Appendix IV. Record Sheet

Dynamics of accommodation study

Record Sheet

Subject's Name: ______________________________ # ________

Subject's Age: ________________ Date: ________________

Habitual VA

Distance OD ______ OS ______ OU ______

Refraction

Dominant Eye (OD / OS)

PD ______

AutoRefraction OD ____________________ VA ______

OS ____________________ VA ______

Subjective Rx OD ____________________ VA ______ }

OS ____________________ VA ______

VD ______

Heterophoria

Cover Test with best refraction Dist ____________________

Near ____________________

Keratometry

OD ____________________

OS ____________________

Amp of accommodation

OD ____________________

OS ____________________

Ocular Health

External

Internal

Remarks (if any): ____

Appendix V. Raw data

A.5.1. Non-Chinese adults

Subject	Myopic sub-groups		Gender	Age	Family of country of origin	Subjective refraction (D) Fs	Fc	Axis	Ocular amplitude of accommodation (D)	Gradient of Accommodative Stimulus-response curve	Tonic accommodation (D)
AE01	\	\	F	19	Indian	-0.25	0	0	8.88	0.70	0.89
AE03	\	\	M	30	British	0	0	0	7.55	1.04	-0.11
AE04	\	\	F	19	British	0.5	-0.25	14	7.61	0.92	1.32
AE07	\	\	F	23	Indian	0	0	0	7.30	0.90	0.43
AE08	\	\	F	19	Indian	0	-0.75	95	8.30	0.50	0.29
AE09	\	\	F	20	Indian	-0.25	0	0	9.66	0.74	1.58
AE10	\	\	F	28	Greek	0	0	0	7.55	0.87	1.50
AE11	\	\	F	19	Cypriot	0	0	0	13.42	0.75	1.10
AE12	\	\	M	20	British	-0.5	0	0	8.27	0.70	0.59
AE14	\	\	M	21	Indian	0.5	-0.5	70	7.76	0.84	0.95
AE16	\	\	M	21	British	-0.25	0	0	8.08	0.85	1.13
AE17	\	\	F	18	Indian	-0.25	0	0	7.51	0.40	0.82
AE18	\	\	F	21	Bangladeshi	0	-0.25	50	8.90	0.60	1.93
AE19	\	\	F	20	Indian	0.5	-0.5	130	10.55	0.88	1.16
AE20	\	\	F	18	Indian	0	0	0	9.72	0.85	1.39
AE21	\	\	M	20	Indian	-0.5	0	0	11:12	0.82	1.53
AE22	\	\	F	21	Bangladeshi	-0.25	0	0	8.48	0.95	1.46
AM01	EOM	PM	M	19	Indian	-9.5	-1.25	35	10.28	0.82	0.60
AM02	EOM	PM	M	19	Indian	-8	-1.25	175	7.41	0.68	0.03
AM04	EOM	SM	F	19	British	-2.25	-0.5	85	15.90	0.63	1.03
AM05	EOM	PM	F	20	Indian	-0.75	0	0	10.69	0.69	0.46
AM06	EOM	SM	F	28	British	-2.75	-0.5	25	7.97	0.99	1.57
AM07	EOM	SM	M	28	British	-2	0	0	7.37	0.75	0.77
AM08	EOM	SM	F	23	British	-6	0	0	5.87	0.63	0.95
AM10	LOM	SM	M	20	Indian	-0.75	-0.5	100	9.50	0.84	1.67
AM11	EOM	SM	M	20	British	-3.25	0	0	10.47	0.85	1.34
AM12	LOM	PM	F	19	Indian	-3.25	-0.75	70	9.68	0.76	0.08
AM13	LOM	PM	F	19	British	-0.75	0	0	11.79	0.81	1.89
AM14	LOM	PM	M	29	British	-3.25	-0.25	180	7.15	0.93	1.20
AM15	EOM	PM	F	19	Indian	-7	-0.5	40	9.62	0.75	1.42
AM16	EOM	PM	F	19	Indian	-6.5	-0.5	175	11.63	0.59	0.95
AM18	EOM	PM	M	21	Indian	-4.25	-0.75	30	7.33	0.84	0.26
AM19	EOM	SM	F	20	Indian	-2.5	-0.25	180	8.64	0.94	0.81
AM20	EOM	SM	F	21	Malaysian	-2.75	-0.75	20	8.70	0.86	1.09
AM21	EOM	PM	M	21	Indian	-0.5	-0.25	160	9.19	0.57	0.87

Subject	NITM (D)									
			after 5 D task					after 2.5 D task		
	1st to 10th sec	21st to 30th sec	1st to 60th sec	61th to 120th sec	121st to 180th sec	1st to 10th sec	21st to 30th sec	1st to 60th sec	61th to 120th sec	121st to 180th sec
AE01	0.52	0.18	0.27	-0.08	-0.14	0.30	0.03	0.07	-0.04	-0.02
AE03	0.17	0.28	0.22	0.15	0.36	0.37	0.03	0.17	0.06	-0.07
AE04	-0.36	0.18	-0.10	-0.21	-0.03	0.30	-0.07	0.16	0.19	0.05
AE07	0.16	0.08	0.06	-0.07	-0.16	-0.13	0.02	-0.06	-0.15	-0.12
AE08	0.71	0.57	0.49	0.19	0.14	0.81	0.18	0.25	-0.07	-0.20
AE09	0.34	0.27	0.30	0.17	0.38	0.46	0.29	0.39	0.19	0.16
AE10	-0.13	-0.36	-0.25	-0.10	0.14	0.66	0.09	0.15	-0.10	0.24
AE11	0.34	0.19	0.22	0.09	-0.05	0.07	-0.28	-0.12	-0.19	-0.26
AE12	0.37	0.19	0.19	0.02	-0.01	-0.10	-0.42	-0.25	-0.13	-0.27
AE14	-0.06	-0.06	-0.18	-0.45	-0.27	-0.26	-0.31	-0.32	-0.22	-0.24
AE16	0.73	0.45	0.36	0.08	-0.04	0.86	0.42	0.50	0.02	-0.21
AE17	0.63	0.03	0.40	0.22	-0.16	0.77	0.26	0.38	0.29	0.01
AE18	0.91	0.90	0.96	0.94	0.93	0.43	-0.09	-0.03	-0.07	-0.21
AE19	0.27	0.02	0.14	0.21	0.05	0.26	-0.46	-0.13	-0.28	-0.07
AE20	0.09	0.25	0.15	-0.14	0.00	0.19	0.16	0.09	-0.23	-0.12
AE21	0.46	0.16	0.20	-0.01	0.19	0.41	0.06	0.10	0.11	0.10
AE22	0.54	0.28	0.38	0.38	0.47	0.33	0.32	0.35	0.39	0.22
AM01	0.11	-0.13	-0.05	-0.09	-0.03	0.26	0.60	0.23	-0.10	-0.28
AM02	0.01	-0.12	-0.06	-0.06	-0.18	0.44	0.40	0.39	0.00	0.12
AM04	0.84	0.06	0.10	0.02	0.05	0.54	0.35	0.26	0.21	0.06
AM05	0.14	0.05	-0.04	-0.17	-0.21	0.33	-0.01	0.10	-0.11	-0.05
AM06	0.47	0.33	0.18	0.02	0.09	0.53	0.27	0.28	0.13	0.18
AM07	0.57	0.36	0.27	0.12	-0.09	0.13	-0.07	-0.03	0.00	0.04
AM08	0.60	0.38	0.42	0.32	0.33	0.00	0.06	-0.01	-0.06	-0.27
AM10	0.26	0.04	0.09	0.00	-0.04	0.36	0.36	0.36	-0.01	-0.01
AM11	0.22	0.12	0.10	-0.11	0.13	0.26	0.18	0.17	0.06	0.17
AM12	0.41	0.06	0.15	0.22	0.14	0.18	0.13	0.09	-0.01	-0.05
AM13	-0.33	0.18	-0.24	-0.25	0.15	0.58	0.53	0.30	0.01	-0.02
AM14	0.34	-0.17	-0.18	-0.39	-0.35	0.84	0.12	0.25	-0.02	0.07
AM15	0.24	0.17	0.01	0.19	0.26	0.34	0.24	0.10	0.14	0.08
AM16	0.56	0.39	0.43	0.15	-0.09	0.42	0.14	0.14	-0.14	-0.08
AM18	0.31	0.24	0.18	0.07	0.30	0.26	0.07	0.16	-0.05	0.13
AM19	-0.07	-0.11	-0.13	-0.24	-0.03	0.23	0.05	0.07	-0.15	-0.03
AM20	-0.07	-0.09	-0.19	-0.30	-0.34	0.00	0.20	0.08	0.01	-0.10
AM21	0.32	0.26	0.21	0.08	-0.17	0.38	0.24	0.41	0.26	0.21

Subject	Accommodative response (D) in NITM experiment					
	Task A	Task B	Task C		Task D	
	Near	Near	Far	Near	Far	Near
AE01	4.04	1.51	0.06	3.91	-0.06	1.85
AE03	3.69	1.91	-0.11	3.48	0.23	1.88
AE04	4.16	2.21	-0.28	4.05	-0.41	2.01
AE07	3.58	1.84	-0.03	3.68	0.12	1.94
AE08	3.51	0.97	-0.31	3.82	-0.19	1.20
AE09	4.41	2.44	0.02	4.21	0.02	2.44
AE10	3.93	1.92	0.06	3.54	-0.16	1.88
AE11	3.43	1.51	-0.16	3.40	-0.13	1.57
AE12	4.35	1.85	0.09	3.99	-0.04	1.68
AE14	3.78	1.97	-0.09	3.93	-0.11	1.89
AE16	4.57	2.38	0.15	4.71	0.16	2.44
AE17	4.26	1.85	0.18	3.82	0.20	2.10
AE18	3.93	2.30	-0.02	3.97	-0.10	2.13
AE19	3.83	1.79	-0.21	3.84	0.15	1.58
AE20	4.52	2.53	-0.14	4.59	-0.19	2.61
AE21	4.43	2.44	-0.10	4.49	-0.02	2.38
AE22	4.47	2.06	-0.09	4.31	-0.13	2.21
AM01	4.30	1.98	-0.05	4.34	-0.27	1.63
AM02	3.96	1.77	0.09	4.03	0.05	1.84
AM04	4.11	2.56	0.00	4.65	-0.14	2.37
AM05	3.88	2.22	0.15	3.99	0.05	2.17
AM06	3.31	1.75	0.08	3.43	0.03	1.83
AM07	3.49	1.30	0.01	3.49	0.02	1.29
AM08	3.74	1.88	-0.07	3.51	0.15	2.05
AM10	3.95	2.43	0.02	3.97	-0.07	2.53
AM11	3.54	1.69	0.00	3.66	0.10	1.82
AM12	3.90	2.23	-0.13	3.80	-0.09	2.10
AM13	4.27	2.43	-0.03	4.19	-0.03	2.61
AM14	4.42	2.82	-0.20	4.92	-0.21	2.72
AM15	4.40	2.27	0.18	4.28	-0.04	2.31
AM16	4.16	1.76	0.10	3.73	-0.05	1.49
AM18	3.56	1.89	-0.06	3.50	-0.09	1.54
AM19	3.93	1.59	-0.09	3.96	-0.06	1.62
AM20	3.42	1.47	0.29	3.56	-0.02	1.49
AM21	3.72	2.15	0.07	4.06	0.23	2.09

Appendix V. A5.2. Chinese adults

Subject	Myopic sub-groups		Gender	Age	Subjective refraction (D)			Ocular amplitude of accommodation (D)	Gradient of Accommodative Stimulus-response curve	Tonic accommodation (D)
					Fs	Fc	Axis			
AE01	\	\	M	24	0	-0.5	95	8.08	0.73	1.14
AE02	\	\	M	21	0.5	-0.75	85	8.15	0.86	0.41
AE03	\	\	M	22	0	-0.25	120	7.69	0.79	1.43
AE04	\	\	F	21	0	0	0	7.71	0.90	1.23
AE05	\	\	F	21	0.25	-0.5	75	8.93	0.74	0.49
AE06	\	\	M	21	0	0	0	8.93	0.76	0.62
AE07	\	\	M	20	0	0	0	8.93	0.98	1.15
AE08	\	\	F	24	0.75	-0.5	135	7.38	1.05	1.13
AE09	\	\	M	22	0.25	-0.25	90	10.52	0.81	0.50
AE10	\	\	M	19	-0.25	-0.5	85	9.22	0.83	0.45
AE11	\	\	F	20	0.25	-0.25	90	9.74	0.80	0.97
AE12	\	\	M	20	0.5	0	0	9.03	1.09	1.06
AE13	\	\	F	21	0	-0.75	170	11.15	0.86	0.91
AE14	\	\	F	22	0.25	0	0	7.76	0.91	1.53
AE15	\	\	M	26	0	-0.5	100	7.67	0.64	1.58
AE16	\	\	M	25	0.25	-0.5	85	8.12	1.08	0.43
AE18	\	\	F	25	0	0	0	9.33	0.75	1.42
AE19	\	\	F	23	0.5	0	0	7.80	0.72	1.52
AE20	\	\	F	22	0.25	-0.25	65	8.15	0.95	1.72
AE21	\	\	F	27	-0.25	0	0	6.42	0.67	1.77
AE23	\	\	F	32	-0.25	-0.25	150	7.65	0.75	1.22
AM01	EOM	SM	M	26	-1.75	-0.75	40	6.96	0.96	-0.33
AM02	EOM	PM	M	27	-8.75	0	0	6.92	0.65	0.93
AM03	LOM	SM	M	23	-0.5	-1.25	5	8.31	0.82	0.12
AM05	EOM	SM	M	28	-3.5	0	0	10.41	0.97	1.45
AM06	LOM	SM	M	21	-1.25	-0.75	150	10.85	0.96	0.17
AM07	LOM	SM	M	26	-1	-0.75	150	9.42	0.75	1.40
AM08	EOM	SM	F	22	-6.25	-1.25	35	7.33	0.90	1.40
AM09	EOM	SM	M	21	-2.25	-0.5	110	8.44	0.99	0.71
AM10	LOM	SM	M	22	-1.5	0	0	9.40	0.79	1.68
AM11	EOM	SM	M	27	-7.75	-1	175	6.58	0.99	0.67
AM12	EOM	SM	F	21	-3.25	-0.75	75	10.04	1.01	1.43
AM13	EOM	SM	M	22	-4	-0.5	45	7.39	1.09	0.48
AM15	EOM	SM	F	24	-9.25	-0.5	150	8.88	0.91	1.25
AM16	EOM	SM	M	25	-3.75	0	0	9.66	0.88	1.07
AM17	EOM	SM	M	29	-4	-0.75	10	7.00	0.75	1.02
AM18	EOM	SM	F	22	-1.75	-0.75	105	13.48	0.82	1.76
AM19	LOM	PM	M	20	-1	0	0	10.26	0.86	1.36
AM20	LOM	SM	M	25	-4	-0.75	15	7.00	0.79	1.15
AM21	EOM	PM	M	26	-5.25	-1	10	7.51	0.78	0.68
AM22	LOM	SM	F	25	-2.5	0	0	8.06	0.78	0.44
AM23	LOM	PM	M	21	-0.75	0	0	8.38	0.73	0.76
AM24	LOM	PM	F	25	-1	-0.5	5	7.50	0.72	1.50

Subject	NITM (D)									
			after 5 D task					after 2.5 D task		
	1st to 10th sec	21st to 30th sec	1st to 60th sec	61th to 120th sec	121st to 180th sec	1st to 10th sec	21st to 30th sec	1st to 60th sec	61th to 120th sec	121st to 180th sec
AE01	0.33	0.13	0.12	0.19	0.09	0.78	-0.06	0.07	-0.06	-0.07
AE02	0.56	0.36	0.41	0.17	0.20	0.22	0.25	0.26	0.18	0.08
AE03	0.40	0.49	0.45	0.36	0.42	0.50	0.36	0.46	0.26	0.36
AE04	0.42	0.16	0.19	0.04	0.01	0.18	-0.11	-0.08	-0.06	-0.03
AE05	-0.12	0.33	0.26	-0.10	-0.12	0.32	0.39	0.22	0.04	0.61
AE06	-0.20	0.04	-0.05	-0.06	-0.16	-0.43	-0.15	-0.23	-0.35	-0.18
AE07	0.30	-0.03	0.01	-0.02	-0.12	0.50	0.14	0.14	-0.02	0.04
AE08	0.58	0.02	0.05	-0.23	-0.33	0.32	0.05	0.08	-0.18	0.08
AE09	0.30	-0.11	0.03	-0.13	-0.09	0.10	0.06	0.04	-0.07	-0.07
AE10	0.32	0.17	0.19	0.06	0.13	0.09	-0.01	-0.03	0.09	0.06
AE11	0.48	0.05	0.06	-0.02	-0.03	0.37	0.09	0.05	-0.10	-0.08
AE12	0.37	0.02	0.19	0.31	0.31	0.34	0.19	0.15	-0.08	-0.01
AE13	0.33	-0.11	0.04	0.01	0.09	0.26	0.05	0.14	0.25	0.38
AE14	0.27	0.18	0.26	0.24	0.29	0.33	0.23	0.26	0.15	0.06
AE15	0.83	0.01	0.11	-0.16	-0.09	0.39	0.27	0.15	-0.01	0.01
AE16	0.43	0.12	0.12	-0.01	0.00	0.28	0.10	0.06	-0.07	-0.01
AE18	-0.20	-0.33	-0.32	-0.32	-0.33	0.12	-0.14	-0.14	-0.26	-0.33
AE19	0.15	-0.33	-0.31	-0.56	-0.47	0.34	-0.07	-0.11	-0.32	-0.21
AE20	0.29	0.02	0.05	-0.02	-0.10	0.05	-0.24	-0.22	-0.19	-0.19
AE21	0.18	0.03	0.02	-0.08	-0.07	0.56	0.50	0.33	0.07	0.01
AE23	0.29	0.04	0.19	0.08	0.23	0.34	0.19	0.17	0.07	0.27
AM01	0.15	0.28	0.04	-0.01	-0.01	0.12	0.08	0.10	0.04	0.00
AM02	0.00	0.12	0.01	-0.02	-0.13	0.08	-0.17	-0.02	0.04	0.18
AM03	-0.25	-0.30	-0.38	-0.38	-0.42	-0.15	0.02	0.06	0.02	0.02
AM05	0.36	0.41	0.37	0.32	0.26	0.21	0.02	0.07	-0.05	-0.06
AM06	0.37	0.07	0.14	-0.06	0.03	0.22	-0.12	-0.02	-0.12	-0.08
AM07	0.25	-0.26	-0.22	-0.31	-0.28	-0.26	-0.30	-0.38	-0.40	-0.13
AM08	0.33	0.72	0.44	0.60	0.26	-0.19	-0.18	-0.14	-0.15	-0.04
AM09	0.10	0.05	-0.01	-0.16	-0.16	0.01	0.06	0.11	0.18	0.20
AM10	0.80	0.17	0.25	-0.04	-0.04	0.36	-0.12	-0.09	-0.06	0.06
AM11	0.50	0.29	0.34	0.13	-0.01	0.33	0.07	0.23	0.12	0.16
AM12	0.00	-0.21	-0.18	-0.14	-0.33	0.31	-0.01	0.00	-0.23	-0.19
AM13	0.65	0.45	0.36	0.25	0.09	0.06	0.03	0.03	0.11	0.14
AM15	0.38	0.17	0.20	0.12	0.13	0.18	0.07	0.08	0.01	0.07
AM16	0.09	-0.14	-0.13	-0.23	-0.23	0.21	0.07	0.07	-0.03	0.00
AM17	0.30	0.00	0.09	-0.02	0.34	0.44	-0.04	0.16	-0.15	-0.12
AM18	0.00	-0.16	-0.11	-0.12	0.04	0.50	-0.06	0.13	0.05	0.02
AM19	1.53	1.21	0.95	0.16	0.08	1.05	-0.02	0.06	-0.28	0.00
AM20	0.11	0.04	0.09	-0.02	-0.01	0.11	0.01	0.01	0.00	0.09
AM21	0.66	0.27	0.26	0.00	0.10	0.50	0.04	0.11	0.08	0.09
AM22	0.14	0.07	0.18	0.00	-0.09	0.14	0.02	0.00	-0.06	-0.12
AM23	0.40	0.30	0.31	0.29	0.23	0.26	-0.11	0.06	-0.06	-0.08
AM24	0.05	-0.05	-0.08	-0.19	-0.23	0.44	0.38	0.29	0.23	0.21

Subject	Accommodative response (D) in NITM experiment					
	Task A	Task B	Task C		Task D	
	Near	Near	Far	Near	Far	Near
AE01	3.20	1.47	0.03	3.19	0.10	1.57
AE02	3.35	1.35	0.16	3.44	0.17	1.94
AE03	3.57	1.47	-0.11	3.36	-0.37	1.54
AE04	4.07	1.79	-0.05	4.11	0.00	2.18
AE05	3.62	2.15	-0.08	3.86	-0.20	2.20
AE06	3.14	1.00	0.09	3.14	0.11	1.01
AE07	3.73	1.80	0.10	4.08	0.11	1.99
AE08	3.93	1.75	0.14	3.31	0.12	1.93
AE09	3.63	2.02	0.02	3.66	0.18	1.82
AE10	3.72	1.72	-0.10	3.94	-0.04	1.84
AE11	3.84	2.02	0.15	4.02	0.27	2.11
AE12	4.39	2.37	-0.06	4.51	0.19	2.29
AE13	3.79	1.86	0.03	3.86	0.04	1.93
AE14	3.39	1.49	-0.15	3.83	-0.10	1.66
AE15	3.58	1.53	0.14	3.58	0.07	1.42
AE16	4.06	2.01	0.04	4.10	0.09	2.17
AE18	3.30	1.37	-0.03	3.49	-0.11	1.46
AE19	3.39	1.51	0.24	3.47	-0.01	1.58
AE20	3.76	1.77	0.03	3.72	0.09	1.92
AE21	3.41	1.16	0.01	3.36	-0.08	1.30
AE23	3.52	2.00	0.16	3.59	-0.03	2.08
AM01	3.45	1.60	-0.05	3.49	-0.01	1.36
AM02	3.92	2.35	0.15	3.69	-0.12	2.14
AM03	3.29	1.13	0.10	3.41	-0.01	1.13
AM05	4.92	2.53	0.06	4.44	0.22	2.80
AM06	3.88	2.25	-0.02	3.88	-0.04	2.07
AM07	3.68	1.32	0.17	3.91	0.06	1.78
AM08	3.86	1.82	-0.15	3.91	0.24	1.59
AM09	3.79	2.11	0.03	3.50	0.02	1.85
AM10	4.80	1.88	0.17	4.68	0.13	1.76
AM11	3.84	1.80	0.30	3.90	0.03	1.89
AM12	3.52	1.63	0.12	3.61	-0.02	1.83
AM13	3.70	1.66	0.06	3.46	0.09	1.91
AM15	3.55	1.61	-0.05	3.50	-0.03	1.74
AM16	4.14	1.78	0.22	4.41	-0.06	1.77
AM17	4.07	2.16	0.19	4.14	0.17	2.24
AM18	3.95	2.24	0.20	4.31	0.16	2.49
AM19	4.34	1.41	-0.06	4.25	-0.05	1.58
AM20	3.61	1.86	-0.17	3.91	-0.11	1.75
AM21	3.50	2.12	-0.17	3.44	-0.23	2.00
AM22	3.83	1.93	0.15	3.96	0.16	2.02
AM23	3.63	1.72	-0.15	3.54	0.03	1.78
AM24	4.38	2.10	0.18	4.24	-0.17	2.18

Appendix V. A5.3. Chinese children (Cross-sectional study)

Subject	Gender	Age	Subjective refraction (D) Fs	Fc	Axis	Ocular amplitude of accommodation (D)	Gradient of Accommodative Stimulus-response curve	Tonic accommodation (D)
KE03	F	9	0.5	0	0	10.61	0.70	0.05
KE04	F	10	0.5	-0.25	20	13.18	0.92	1.90
KE05	M	10	-0.25	-0.5	10	10.34	0.87	0.32
KE06	F	10	-0.25	-0.25	180	10.40	0.76	0.81
KE07	F	10	-0.25	0	0	12.64	0.64	0.66
KE08	M	12	0.5	-0.25	180	11.34	0.69	1.05
KE09	F	10	0.75	-0.5	100	9.86	0.64	0.33
KE10	F	9	0.25	0	0	10.16	1.08	0.54
KM01	M	12	-5	-1	170	11.29	0.64	-0.21
KM02	M	11	-5.25	-0.5	30	9.30	0.47	0.06
KM03	F	12	-6	-0.25	15	11.15	0.96	1.19
KM04	M	12	-4.25	-1.25	20	10.78	0.53	0.18
KM05	M	10	-3.5	-0.5	15	10.01	0.48	0.18
KM07	F	12	-2.25	-0.5	120	9.19	0.72	1.50
KM08	F	12	-2.75	-1.25	5	10.44	1.07	0.58
KM09	M	11	-5.75	0	0	9.25	0.76	-0.24
KM10	M	10	-5.25	-1	15	10.59	0.40	0.52
KM11	F	10	-3.75	-1	15	10.25	0.85	0.79
KM12	F	11	-4	-1	20	10.19	0.73	0.11
KM13	F	11	-1.25	0	0	8.29	0.88	0.48
KM14	M	10	-5.25	-0.75	5	9.95	0.64	-0.18
KM15	M	10	-1.75	-0.75	5	8.51	0.61	0.17
KM16	F	12	-4	-1	165	8.08	0.65	0.49
KM18	M	9	-2.5	0	0	10.64	0.74	0.15
KM19	F	10	-6	-1.25	10	8.75	0.68	0.73
KM20	M	12	-5	-0.5	15	10.03	0.68	0.01
KM21	M	10	-1.5	-0.5	165	10.09	0.68	0.75
KM22	M	12	-1.5	0	0	10.88	0.75	0.42
KM23	M	11	-1	-0.75	5	9.42	0.51	0.73
KM24	F	11	-5.25	-1.25	15	8.55	0.90	0.54
KM25	M	10	-1.25	-0.75	175	9.37	0.32	0.25

Subject	NITM (D)									
			after 5 D task					after 2.5 D task		
	1st to 10th sec	21st to 30th sec	1st to 60th sec	61th to 120th sec	121st to 180th sec	1st to 10th sec	21st to 30th sec	1st to 60th sec	61th to 120th sec	121st to 180th sec
KE03	-0.14	-0.19	-0.17	-0.05	-0.04	0.08	0.15	0.07	-0.08	-0.18
KE04	0.82	0.30	0.48	0.05	0.14	0.08	0.21	0.14	0.02	0.00
KE05	-0.05	-0.22	-0.24	-0.49	-0.37	0.66	-0.72	0.10	0.28	-0.32
KE06	0.32	0.09	0.16	0.23	0.14	-0.28	-0.33	-0.03	-0.24	0.12
KE07	0.33	0.15	0.23	0.11	-0.07	-0.17	0.10	-0.12	-0.32	-0.19
KE08	-0.04	-0.28	-0.26	-0.18	-0.26	-0.17	-0.57	-0.40	-0.50	-0.48
KE09	-0.59	-0.26	-0.52	-0.33	0.52	-0.36	-0.53	-0.26	0.00	0.04
KE10	0.23	0.07	0.22	0.09	0.01	0.33	-0.08	0.01	0.28	-0.54
KM01	1.33	0.38	0.71	0.24	0.52	0.05	-0.01	0.13	-0.25	0.06
KM02	0.19	-0.46	-0.16	0.30	-0.08	-0.16	-0.38	-0.02	0.17	0.28
KM03	-0.03	0.07	-0.07	-0.70	-0.69	-0.18	0.00	-0.04	0.04	0.18
KM04	-0.32	-0.44	-0.49	-0.56	-0.49	-0.04	0.00	-0.08	-0.11	-0.17
KM05	0.91	0.83	0.69	0.44	0.45	-0.57	-0.13	-0.36	-0.80	-0.89
KM07	0.22	0.12	0.00	0.11	0.05	0.27	0.30	0.27	-0.03	0.01
KM08	-0.99	-0.43	-0.65	-0.17	-0.21	-0.87	-0.48	-0.52	-0.23	-0.89
KM09	0.21	0.72	0.34	0.17	0.59	-0.15	0.19	0.02	-0.18	-0.41
KM10	-0.24	0.45	0.18	-0.21	-0.55	-0.58	-0.26	-0.25	-0.19	-0.20
KM11	0.29	0.24	0.23	0.06	-0.02	0.41	-0.35	-0.06	-0.12	-0.07
KM12	-0.25	-0.18	-0.17	-0.31	-0.24	0.27	0.21	0.16	0.20	0.12
KM13	-0.24	0.38	0.11	0.24	0.12	0.24	0.32	0.24	0.38	0.24
KM14	0.44	-0.02	-0.06	-0.08	0.02	0.73	-0.35	0.06	0.15	0.08
KM15	-0.29	-0.54	-0.11	0.07	-0.08	0.01	0.14	0.09	0.19	0.32
KM16	0.82	0.25	0.44	0.26	0.20	-0.25	0.07	0.26	0.07	-0.18
KM18	0.59	-0.01	0.29	0.32	0.16	-0.07	0.27	-0.25	-0.63	-0.07
KM19	0.28	-0.04	0.01	-0.24	-0.37	0.23	-0.16	-0.08	-0.05	-0.01
KM20	-0.94	-0.60	-0.45	-0.44	-0.32	-0.01	-0.44	-0.05	-0.16	-0.08
KM21	0.14	0.20	0.22	0.21	0.25	0.12	-0.16	-0.12	0.15	0.08
KM22	-0.17	-0.26	-0.11	-0.02	-0.03	0.17	-0.08	-0.04	-0.43	-0.41
KM23	0.12	0.88	0.37	0.50	0.13	-0.78	-0.42	-0.75	-0.46	-0.61
KM24	0.07	0.05	0.11	-0.11	-0.28	0.17	-0.24	-0.03	-0.09	-0.08
KM25	-0.64	-0.33	-0.17	-0.14	-0.27	-0.28	-0.06	-0.01	-0.17	0.24

Subject	Accommodative response (D) in NITM experiment					
	Task A	Task B	Task C		Task D	
	Near	Near	Far	Near	Far	Near
KE03	3.87	1.50	-0.06	3.78	-0.07	1.50
KE04	3.78	1.61	-0.05	3.93	-0.06	1.57
KE05	5.23	2.24	-0.04	5.14	0.01	2.20
KE06	3.57	1.40	-0.04	3.59	-0.06	1.47
KE07	3.49	1.35	-0.07	4.01	-0.10	1.47
KE08	3.83	1.49	0.01	3.83	0.11	1.54
KE09	3.69	1.88	0.02	3.88	0.29	1.89
KE10	3.64	1.74	0.09	3.43	0.03	1.88
KM01	3.87	2.21	-0.83	3.56	0.11	2.40
KM02	4.00	1.49	-0.30	4.35	-0.28	1.67
KM03	3.51	1.64	0.05	3.44	0.04	1.38
KM04	4.13	1.24	0.20	3.63	0.09	1.39
KM05	3.77	1.57	-0.86	3.66	0.00	1.67
KM07	3.77	1.51	-0.04	4.28	0.07	1.81
KM08	4.58	1.55	0.42	4.45	-0.02	1.55
KM09	4.01	1.38	0.02	3.79	0.01	1.34
KM10	4.02	2.18	0.29	3.89	0.67	2.20
KM11	3.53	1.52	-0.42	3.72	-0.08	1.69
KM12	4.66	1.68	0.22	5.67	-0.09	1.64
KM13	4.07	2.44	0.44	3.97	-0.01	2.38
KM14	6.35	3.31	-0.20	5.97	-0.25	1.85
KM15	3.91	1.97	0.23	3.94	0.04	1.87
KM16	3.41	1.71	0.01	3.06	0.24	1.49
KM18	4.24	1.55	-0.42	4.03	0.09	1.42
KM19	3.62	1.78	-0.24	3.72	-0.17	1.64
KM20	4.79	1.53	0.31	4.30	0.36	1.58
KM21	3.65	1.20	0.04	3.92	0.10	1.23
KM22	5.13	1.66	0.01	4.66	0.24	1.61
KM23	3.89	1.68	-0.09	3.98	0.39	1.73
KM24	3.65	1.68	-0.03	3.64	0.00	1.67
KM25	4.40	1.95	0.27	4.32	0.15	1.77

Appendix V. A5.4. Chinese children (Longitudinal study)

Subject	EMM_EMM / EMM_M	Gender	Age	Subjective refraction (D) Visit A Fs	Visit A Fc	Visit A Axis	Visit B Fs	Visit B Fc	Visit B Axis	Visit C Fs	Visit C Fc	Visit C Axis
KE03	EMM_EMM	F	9	0.5	0	0	0.25	-0.25	175	0.25	-0.25	15
KE04	EMM_M	F	10	0.5	-0.25	20	0	-0.5	180	-0.25	-0.5	180
KE05	EMM_M	M	10	-0.25	-0.5	10	-0.5	-1	180	-0.75	-1	10
KE07	EMM_M	F	10	-0.25	0	0	-0.5	0	0	-0.75	0	0
KE08	EMM_EMM	M	12	0.5	-0.25	180	0.25	0	0	0.5	0	0
KE09	EMM_EMM	F	10	0.75	-0.5	100	0.25	0	0	0.25	-0.25	90
KM01	\	M	12	-5	-1	170	-5.75	-0.75	180	-6	-1	180
KM03	\	F	12	-6	-0.25	15	-6.5	0	0	-6.75	-0.5	180
KM04	\	M	12	-4.25	-1.25	20	-4.5	-1	20	-5.25	-1	20
KM05	\	M	10	-3.5	-0.5	15	-3.5	-0.75	15	-3.75	-0.5	180
KM08	\	F	12	-2.75	-1.25	5	-3	-1.25	10	-3	-1.25	5
KM09	\	M	11	-5.75	0	0	-6	-0.75	100	-6.25	-0.25	110
KM10	\	M	10	-5.25	-1	15	-5.25	-1	10	-5.25	-1.25	25
KM11	\	F	10	-3.75	-1	15	-4.75	-1	15	-5	-1	10
KM12	\	F	11	-4	-1	20	-3.75	-1	15	-4	-0.5	15
KM13	\	F	11	-1.25	0	0	-1.25	0	0	-1.75	0	0
KM16	\	F	12	-4	-1	165	-4.5	-0.75	165	-5.25	-0.75	160
KM20	\	M	12	-5	-0.5	15	-5.5	-0.5	15	-5.75	-0.75	30
KM21	\	M	10	-1.5	-0.5	165	-1.5	-0.5	170	-1.75	-0.5	175
KM22	\	M	12	-1.5	0	0	-2	0	0	-1.5	-0.5	60
KM23	\	M	11	-1	-0.75	5	-1.25	0	0	-1.25	-0.75	175
KM24	\	F	11	-5.25	-1.25	15	-5.5	-1.25	15	-5.75	-1.5	10

Subject	Ocular amplitude of accommodation (D)			Gradient of Accommodative stimulus-response curve			Tonic accommodation (D)		
	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C
KE03	10.61	10.90	12.75	0.70	0.97	0.93	0.05	0.36	1.22
KE04	13.18	13.35	13.28	0.92	0.81	0.86	1.90	1.57	1.43
KE05	10.37	11.00	10.20	0.87	0.71	0.85	0.32	1.10	0.76
KE07	12.64	14.64	13.20	0.64	0.86	0.83	0.66	1.03	1.05
KE08	11.34	12.42	11.37	0.69	0.88	0.81	1.05	0.90	0.35
KE09	9.83	8.98	7.32	0.64	0.94	0.96	0.33	1.09	0.99
KM01	11.29	11.15	10.42	0.64	0.97	0.71	-0.21	0.24	1.44
KM03	11.15	9.77	9.34	0.96	0.95	1.07	1.19	0.99	1.06
KM04	10.78	10.76	9.93	0.53	0.63	0.75	0.18	-0.39	0.81
KM05	10.01	7.82	7.05	0.48	0.54	0.85	0.18	0.13	0.43
KM08	10.44	10.73	12.41	1.07	0.93	1.07	0.58	1.25	1.52
KM09	9.25	9.80	9.13	0.76	0.84	0.94	-0.24	0.78	0.61
KM10	10.59	11.87	14.26	0.40	0.82	0.54	0.52	0.87	0.47
KM11	10.25	10.70	11.29	0.85	0.76	0.84	0.79	1.23	1.33
KM12	10.19	12.25	9.90	0.73	0.75	0.81	0.11	0.56	0.27
KM13	8.29	7.50	8.97	0.88	0.64	0.87	0.48	0.85	0.94
KM16	8.08	10.11	7.89	0.65	0.88	0.76	0.49	1.42	1.39
KM20	10.03	9.93	9.18	0.68	0.88	0.73	0.01	0.07	0.24
KM21	10.09	10.82	10.76	0.68	0.69	0.71	0.75	0.72	1.16
KM22	10.88	9.66	9.34	0.75	0.69	0.53	0.42	0.16	1.04
KM23	9.42	9.45	10.12	0.51	0.65	0.76	0.73	1.14	0.66
KM24	8.55	6.15	6.54	0.90	0.37	0.56	0.54	0.23	1.13

NITM (D)

after 5.0 D task

Subject	1st to 10th sec			21st to 30th sec			1st to 60th sec			61th to 120th sec			121st to 180th second		
	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C
KE03	-0.14	-0.06	-0.02	-0.19	-0.02	-0.13	-0.17	-0.05	-0.11	-0.05	-0.01	-0.12	-0.04	-0.08	-0.02
KE04	0.82	0.21	0.53	0.30	0.01	0.19	0.48	0.08	0.35	0.05	0.19	0.24	0.14	0.11	0.36
KE05	-0.05	0.26	0.32	-0.22	0.19	0.24	-0.24	-0.02	0.19	-0.49	-0.10	0.05	-0.37	-0.18	-0.28
KE07	0.33	0.14	0.19	0.15	-0.09	0.16	0.23	-0.03	0.06	0.11	-0.29	-0.01	-0.07	-0.15	0.03
KE08	-0.04	-0.23	0.36	-0.28	-0.20	0.32	-0.26	-0.16	0.30	-0.18	-0.35	0.13	-0.26	-0.12	0.24
KE09	-0.59	0.40	0.06	-0.26	0.18	-0.24	-0.52	0.41	-0.02	-0.33	0.30	0.34	0.52	0.18	0.36
KM01	1.33	0.10	0.16	0.38	-0.22	-0.22	0.71	-0.12	-0.11	0.24	-0.32	-0.14	0.52	-0.43	0.04
KM03	-0.03	0.22	-0.05	0.07	0.02	-0.19	-0.07	-0.07	-0.22	-0.70	-0.21	-0.04	-0.69	-0.06	0.12
KM04	-0.32	0.21	0.51	-0.44	-0.40	0.20	-0.49	0.24	0.14	-0.56	0.11	0.12	-0.49	0.21	0.10
KM05	0.91	-0.18	0.22	0.83	0.28	-0.03	0.69	-0.45	-0.09	0.44	-0.40	0.04	0.45	-0.23	0.13
KM08	-0.99	-0.02	0.40	-0.43	0.15	0.39	-0.65	0.16	0.26	-0.17	0.10	0.24	-0.21	-0.07	0.38
KM09	0.21	-0.15	0.07	0.72	0.27	0.31	0.34	0.23	0.31	0.17	0.24	0.26	0.59	0.19	0.20
KM10	-0.24	0.18	0.37	0.45	0.01	0.31	0.18	-0.29	0.17	-0.21	-0.19	0.03	-0.55	-0.01	0.01
KM11	0.29	0.05	0.16	0.24	0.13	0.11	0.23	0.09	0.05	0.06	0.33	0.06	-0.02	-0.14	0.10
KM12	-0.25	0.11	0.79	-0.18	-0.01	0.38	-0.17	-0.13	0.47	-0.31	-0.05	0.15	-0.24	0.18	0.29
KM13	-0.24	0.42	0.60	0.38	0.53	0.34	0.11	-0.12	0.32	0.24	-0.32	0.01	0.12	-0.39	-0.07
KM16	0.82	-0.22	0.26	0.25	0.25	0.23	0.44	0.81	0.20	0.26	0.63	0.10	0.20	0.78	-0.04
KM20	-0.94	0.01	-0.05	-0.60	-0.06	-0.10	-0.45	-0.29	-0.13	-0.44	-0.33	-0.12	-0.32	-0.34	0.03
KM21	0.14	0.52	0.29	0.20	0.22	-0.02	0.22	0.02	0.12	0.21	0.03	0.22	0.25	0.00	-0.33
KM22	-0.17	-0.15	0.48	-0.26	0.24	0.57	-0.11	-0.07	0.37	-0.02	-0.24	0.51	-0.03	0.46	0.46
KM23	0.12	0.36	0.36	0.88	-0.13	0.35	0.37	0.12	0.36	0.50	-0.05	0.24	0.13	-0.08	0.37
KM24	0.07	0.18	0.19	0.05	0.05	0.13	0.11	0.10	0.17	-0.11	0.08	0.07	-0.28	-0.03	-0.03

NITM (D)

after 2.5 D task

Subject	1st to 10th second			21st to 30th second			1st to 60th second		
	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C
KE03	0.08	0.33	0.04	0.15	0.07	-0.10	0.07	0.12	-0.03
KE04	0.08	0.20	0.05	0.21	0.12	-0.07	0.14	0.12	-0.16
KE05	0.66	-0.03	0.34	-0.72	-0.29	0.38	0.10	-0.26	0.17
KE07	-0.17	0.02	-0.21	0.10	-0.07	0.08	-0.12	-0.02	0.05
KE08	-0.17	-0.04	0.11	-0.57	-0.06	-0.01	-0.40	-0.07	0.05
KE09	-0.36	-0.02	-0.10	-0.53	-0.01	-0.26	-0.26	-0.01	-0.21
KM01	0.05	0.25	0.21	-0.01	-0.06	0.08	0.13	-0.05	0.04
KM03	-0.18	-0.08	-0.08	0.00	0.03	-0.23	-0.04	-0.02	-0.12
KM04	-0.04	0.34	0.26	0.00	-0.15	0.10	-0.08	0.09	0.02
KM05	-0.57	0.20	-0.11	-0.13	0.66	0.18	-0.36	0.32	0.18
KM08	-0.87	0.19	0.27	-0.48	0.09	0.07	-0.52	0.20	0.00
KM09	-0.15	-0.12	-0.18	0.19	0.10	-0.24	0.02	0.01	-0.25
KM10	-0.58	0.12	0.45	-0.26	-0.10	0.01	-0.25	-0.03	0.07
KM11	0.41	0.06	0.54	-0.35	-0.08	0.34	-0.06	-0.04	0.24
KM12	0.27	0.16	-0.03	0.21	-0.56	0.03	0.16	-0.20	0.09
KM13	0.24	0.39	0.10	0.32	-0.10	0.10	0.24	-0.14	0.16
KM16	-0.25	0.27	-0.07	0.07	-0.23	0.08	0.26	-0.12	-0.13
KM20	-0.01	-0.01	0.29	-0.44	-0.15	-0.24	-0.05	-0.06	0.08
KM21	0.12	-0.48	0.55	-0.16	0.20	0.03	-0.12	-0.48	0.24
KM22	0.17	-0.17	0.20	-0.08	-0.09	-0.14	-0.04	-0.05	-0.04
KM23	-0.78	0.63	0.68	-0.42	0.24	0.04	-0.75	0.41	0.24
KM24	0.17	0.41	0.09	-0.24	0.06	0.05	-0.03	0.09	0.07

Subject	61th to 120th second			121st to 180th second		
	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C
KE03	-0.08	0.08	-0.05	-0.18	0.00	-0.04
KE04	0.02	0.15	-0.42	0.00	0.16	-0.42
KE05	0.28	-0.45	0.15	-0.32	-0.46	-0.02
KE07	-0.32	-0.05	-0.08	-0.19	-0.01	-0.04
KE08	-0.50	-0.14	-0.10	-0.48	-0.17	-0.10
KE09	0.00	0.01	-0.21	0.04	0.00	-0.19
KM01	-0.25	-0.23	-0.06	0.06	-0.34	-0.16
KM03	0.04	-0.04	-0.06	0.18	-0.04	-0.03
KM04	-0.11	0.23	-0.10	-0.17	0.06	0.12
KM05	-0.80	0.12	0.22	-0.89	0.13	0.30
KM08	-0.23	0.36	-0.10	-0.89	0.14	-0.17
KM09	-0.18	-0.39	-0.15	-0.41	-0.24	-0.02
KM10	-0.19	0.11	-0.12	-0.20	-0.06	-0.04
KM11	-0.12	-0.08	0.07	-0.07	-0.01	-0.01
KM12	0.20	-0.25	0.00	0.12	-0.07	-0.07
KM13	0.38	-0.30	0.08	0.24	-0.25	0.23
KM16	0.07	-0.35	-0.05	-0.18	0.10	-0.09
KM20	-0.16	-0.08	0.02	-0.08	-0.15	-0.02
KM21	0.15	-0.48	0.29	0.08	-0.48	-0.17
KM22	-0.43	0.03	-0.10	-0.41	-0.20	0.23
KM23	-0.46	0.43	0.12	-0.61	0.54	0.39
KM24	-0.09	-0.03	0.12	-0.08	0.23	0.14

Accommodative response (D) in NITM experiment

Subject	Task A			Task B			Task C						Task D					
	Near			Near			Far			Near			Far			Near		
	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C	Visit A	Visit B	Visit C
KE03	3.87	3.28	3.52	1.50	1.77	1.45	-0.06	0.03	0.08	3.78	3.32	3.58	-0.07	0.00	0.01	1.50	1.19	1.34
KE04	3.78	3.23	3.61	1.61	1.19	1.31	-0.05	-0.09	-0.35	3.93	3.18	3.45	-0.06	-0.14	0.01	1.57	0.99	1.62
KE05	5.23	3.81	3.50	2.24	1.90	1.89	-0.04	0.08	0.34	5.14	4.16	3.47	0.01	0.02	0.20	2.20	1.79	1.98
KE07	3.49	3.62	3.72	1.35	1.63	1.87	-0.07	0.09	0.01	4.01	3.46	3.96	-0.10	0.01	-0.06	1.47	1.63	1.91
KE08	3.83	3.17	3.79	1.49	1.32	1.72	0.01	-0.14	-0.10	3.83	3.31	3.51	0.11	-0.12	0.00	1.54	1.33	1.81
KE09	3.69	3.83	3.93	1.88	1.97	1.69	0.02	0.08	-0.10	3.88	3.78	4.14	0.29	0.09	0.09	1.89	2.00	1.80
KM01	3.87	3.17	4.08	2.21	1.08	1.91	-0.83	-0.10	0.17	3.56	3.11	3.58	0.11	-0.37	0.15	2.40	1.08	2.30
KM03	3.51	3.68	3.90	1.64	1.85	2.05	0.05	-0.14	-0.07	3.44	3.74	3.80	0.04	0.01	-0.10	1.38	1.84	2.00
KM04	4.13	3.60	3.86	1.24	1.33	1.71	0.20	-0.10	0.10	3.63	3.40	4.01	0.09	-0.20	0.18	1.39	1.22	1.86
KM05	3.77	3.55	3.52	1.57	1.20	1.53	-0.86	-0.19	-0.01	3.66	3.99	3.57	0.00	-0.17	-0.09	1.67	1.54	1.61
KM08	4.58	3.64	3.64	1.55	2.00	1.63	0.42	0.21	-0.09	4.45	3.76	4.02	-0.02	0.28	-0.05	1.55	1.68	1.44
KM09	4.01	3.37	3.63	1.38	1.31	1.62	0.02	0.05	-0.12	3.79	3.62	3.91	0.01	-0.04	0.12	1.34	1.31	1.77
KM10	4.02	3.61	3.65	2.18	1.64	1.63	0.29	-0.10	-0.04	3.89	3.53	3.85	0.67	0.09	0.01	2.20	1.65	1.66
KM11	3.53	3.69	3.92	1.52	1.92	1.66	-0.42	0.24	0.08	3.72	3.82	3.75	-0.08	0.46	0.04	1.69	2.20	1.84
KM12	4.66	3.45	3.59	1.68	2.05	1.19	0.22	0.14	-0.08	5.67	3.60	3.57	-0.09	0.11	-0.01	1.64	2.23	1.39
KM13	4.07	3.74	3.71	2.44	1.61	1.58	0.44	0.08	0.11	3.97	3.94	3.57	-0.01	0.09	0.06	2.38	1.89	1.63
KM16	3.41	3.95	4.05	1.71	2.15	2.53	0.01	0.50	-0.01	3.06	3.83	3.84	0.24	0.27	0.23	1.49	2.13	2.43
KM20	4.79	3.52	3.97	1.53	1.69	1.83	0.31	-0.19	-0.05	4.30	3.51	3.71	0.36	-0.11	-0.11	1.58	1.81	1.91
KM21	3.65	3.57	3.95	1.20	2.27	1.47	0.04	-0.25	0.06	3.92	3.69	3.78	0.10	-0.20	-0.07	1.23	1.18	1.98
KM22	5.13	3.42	4.00	1.66	1.15	1.77	0.01	-0.07	-0.05	4.66	3.48	4.25	0.24	-0.01	-0.03	1.61	1.16	1.54
KM23	3.89	3.66	3.67	1.68	1.89	1.74	-0.09	0.07	-0.08	3.98	3.63	3.74	0.39	-0.06	0.10	1.73	1.75	1.69
KM24	3.65	3.05	3.54	1.68	1.30	1.88	-0.03	0.01	0.03	3.64	3.28	3.79	0.00	0.02	-0.02	1.67	1.26	1.53

Appendix VI. Additional results for comparison between Indians and non-Chinese adults

Nineteen Indians (9 emmetropes and 10 myopes) and 16 non-Chinese adults (8 emmetropes and 8 myopes) were recruited in the UK study. Indians were younger than non-Chinese adults (19.74 ± 1.20 years versus 22.88 ± 4.15 years) (Unpaired t-test with Welch correction, $t = 2.93$, $df = 17$, $p < 0.05$).

Unless specified, two-way ANCOVA tests, with refractive groups (emmetropes and myopes) and race were set as independent variables and age was set as covariate, were performed to investigate the effect of refractive groups and race on accommodative responses, and any possible interaction between these two factors.

A6.1. Refractive error

The mean refractive errors of emmetropes for Indians and non-Chinese adults were – 0.12 ± 0.26 D and – 0.09 ± 0.26 D respectively. There was no significant difference between their refractive errors (Unpaired t-test, $t = 0.25$, $df = 15$, $p > 0.05$).

The mean refractive errors of myopes for Indians and non-Chinese were – 4.25 ± 0.97 D and – 2.88 ± 0.89 D respectively. There was no significant difference between their refractive errors (Unpaired t-test with Welch correction, $t = 1.27$, df

$= 13$, $p > 0.05$).

A6.2. Amplitude of accommodation

Two-way ANCOVA showed similar amplitude of accommodation between Indians (9.19 ± 1.34 D) and non-Chinese adults (9.07 ± 2.61 D) ($F_{(1,30)} = 2.21$, $p > 0.05$). There was no significant difference between refractive groups ($F_{(1, 30)} = 1.39$, $p > 0.05$) and no interaction effect between refractive groups and ethnic groups ($F_{(1,30)} = 0.28$, $p > 0.05$).

A6.3. Accommodative stimulus-response curve

The gradient of the accommodative stimulus-response curve of Indians (0.74 ± 0.14) and non-Chinese adults (0.82 ± 0.13) were similar (Two-way ANCOVA: $F_{(1,30)} = 0.12$, $p > 0.05$). There was no significant difference between refractive groups ($F_{(1, 30)} = 0.15$, $p > 0.05$) and no interaction effect between refractive groups and ethnic groups ($F_{(1,30)} = 0.49$, $p > 0.05$).

A6.4. Tonic accommodation

Indians demonstrated a lower tonic accommodation (0.85 ± 0.51 D) than that of non-Chinese adults (1.17 ± 0.50 D) (Two-way ANCOVA: $F_{(1,30)} = 5.37$, $p < 0.05$). There was no significant difference between refractive groups ($F_{(1, 30)} = 0.16$, $p > 0.05$) and no interaction effect between refractive groups and ethnic groups ($F_{(1,30)} = 1.76$, $p > 0.05$).

A6.5. NITM

	Indians		Non-Chinese adults	
	Emmetropes (n = 9)	Myopes (n = 10)	Emmetropes (n = 8)	Myopes (n = 8)
	1st 10-seconds post-change			
Task A (5.0 D to 0.0 D)	0.35 ± 0.26 D**	0.23 ± 0.19 D**	0.32 ± 0.42 D	0.33 ± 0.38 D**
Task B (2.5 D to 0.0 D)	0.31 ± 0.36 D**	0.32 ± 0.08 D**	0.36 ± 0.30 D**	0.36 ± 0.31 D**
	3rd 10-seconds post-change			
Task A (5.0 D to 0.0 D)	0.17 ± 0.19 D**	0.08 ± 0.18 D	0.27 ± 0.35 D	0.15 ± 0.21 D
Task B (2.5 D to 0.0 D)	0.03 ± 0.25 D	0.22 ± 0.19 D**	0.00 ± 0.28 D	0.21 ± 0.18 D**

Table A6.5.1. The mean (± SD) NITM of Indians and non-Chinese adults in the first 10-seconds and the third 10-seconds post-change. ** indicates a difference from the baseline accommodative response D2 which is statistically significant at the 0.05 level.

Three-way ANCOVA showed no difference in NITM in either the first 10-seconds or the third 10-seconds post-change between Indians and non-Chinese adults (1st 10-seconds: $F_{(1,61)} = 0.19$, $p > 0.05$; 3rd 10-seconds: $F_{(1,61)} = 1.08$, $p > 0.05$). Emmetropes and myopes had similar NITM in either the first 10-seconds or the third 10-seconds post-change (1st 10-seconds: $F_{(1,61)} = 0.14$, $p > 0.05$; 3rd 10-seconds: $F_{(1,61)} = 0.99$, $p > 0.05$). There was no dose effect on NITM at different time intervals post-change (1st 10-seconds: $F_{(1,61)} = 0.20$, $p > 0.05$; 3rd 10-seconds: $F_{(1,61)} = 0.90$, $p > 0.05$). Only the interaction between refractive groups and dose in the third 10-seconds post-change was significant ($F_{(1,61)} = 7.45$, $p < 0.05$). The difference in NITM between 5.0 D and 2.5 D was greater in emmetropes than in myopes (Figure A6.5.1.), and the difference in NITM between emmetropes and myopes was greater after 2.5 D than after 5.0 D tasks (Figure A6.5.2.).

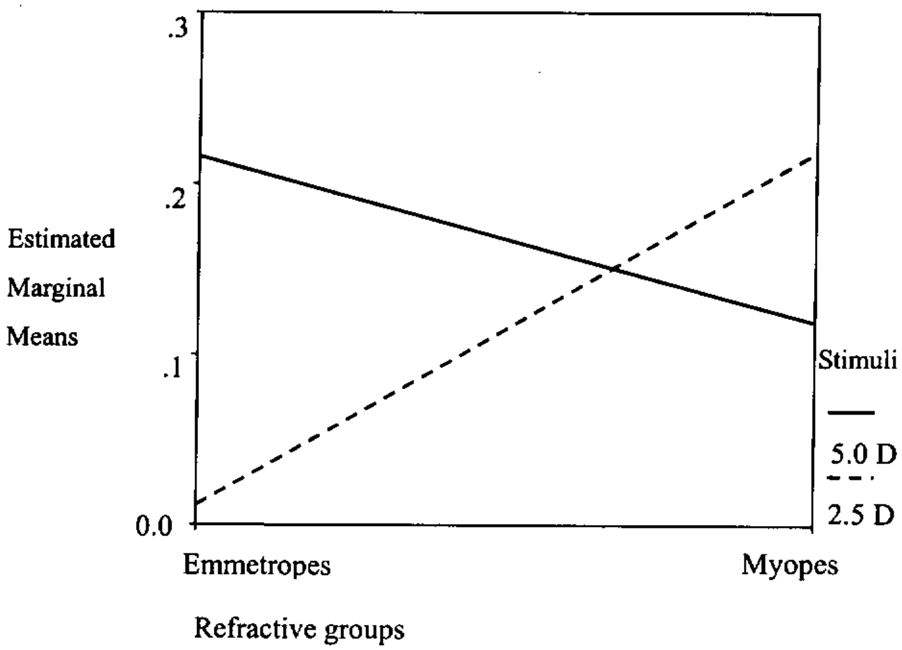

Figure A6.5.1. Interaction plot with stimuli against refractive groups.

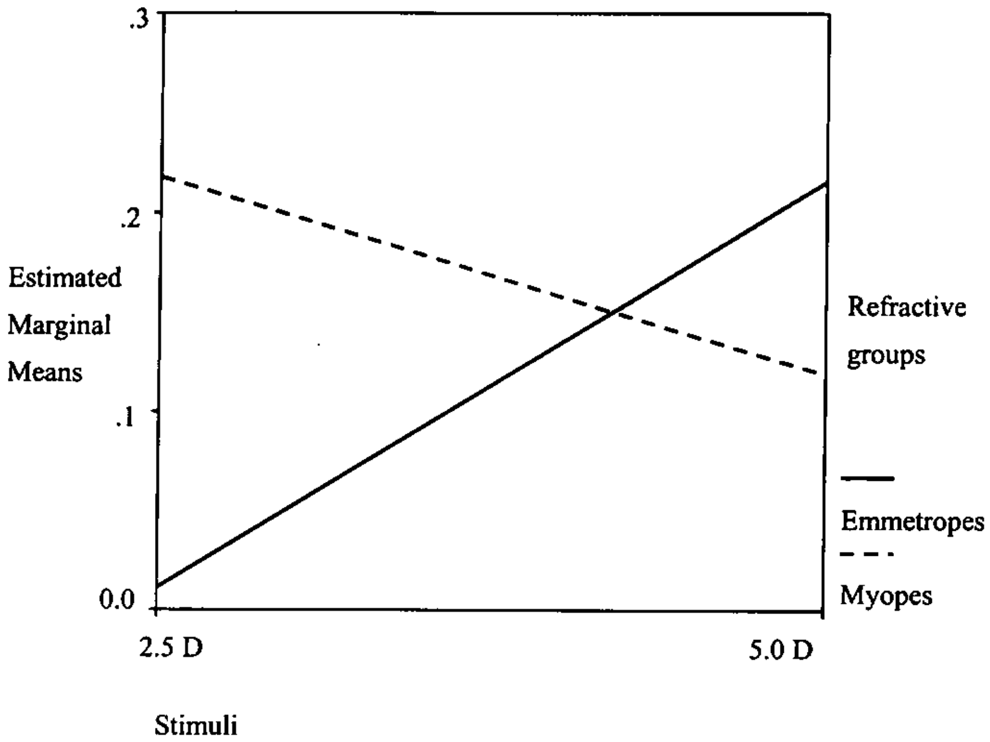

Figure A6.5.2. Interaction plot with refractive groups against stimuli.

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