Original Article

Accommodative Stimulus Response Curve of Emmetropes and Myopes

Anna CH Yeo,[1] *B Optom (Hons), M App Sc*, Kok Kai Kang,[2] *Dip Optom*, Wilfred Tang,[3] *BSc (Optom), PhD*

Abstract

Introduction: Myopes are suspected to be poorer at responding to accommodative stimuli than emmetropes, and this may worsen the degree of their myopia. The study aims to compare the abilities of young adult emmetropes and myopes in responding to accommodative stimuli, as indicated by their Accommodation Stimulus Response Curves (ASRCs) in a predominantly Chinese population. Materials and Methods: Seventeen emmetropes and 33 myopes aged between 16 and 23 years (mean, 18.6 ± 1.2) were recruited, of whom 11 were progressing and 22 were non-progressing myopes. The ASRC gradients of subjects were measured using the methods of decreasing distance series (DDS), positive (PLS) and negative lens series (NLS). Results: The ASRC is method dependent. The gradients of the curves are significantly different among 3 methods of measurement using single-factor ANOVA ($F_{3,057}$ = 44.815, *P* <0.01). The slopes of the accommodative errors of all subjects were steeper using the NLS method, and the lags of accommodation increased with elevated demands. No significant differences in ASRC gradients were found between emmetropes, non-progressing myopes and progressing myopes for the range of accommodative demands for each method. Progressing myopes showed the highest error towards the higher demand compared with the emmetropes and non-progressing myopes. Conclusion: Accommodative responses of myopes were more sluggish though there were no statistical differences in ASRC gradients between emmetropes and myopes. It is not certain if the poorer accommodative responses were a cause, or a consequence, of myopia.

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Key words: Accommodative lag, Accommodative response, Chinese population, Myopia control, Near work

Introduction

There is a strong association between myopia and near work, and it has been reported that the rapid rise in the prevalence of myopia in Singaporean children may be related to an increase in near work demands such as reading.[1-5] Although the mechanism by which near work affects myopia progression is not known, prolonged chronic accommodation during close work has been implicated in myopia. Supporting evidence for this theory provided by several researchers[6-8] have demonstrated that myopic subjects tend to accommodate less to near targets, or that they exhibited a greater lag of accommodation than non-myopic subjects. This inaccuracy of accommodation may form part of the underlying mechanism, or be a consequence, of myopia development. However, findings from other studies do not support this linkage. Studies by Ramsdale[9] and Nakasuka et al[10] failed to demonstrate that myopic subjects accommodate significantly less than emmetropic subjects.

Various studies have used different experimental protocols and approaches to investigate the accommodative responses of myopes. Gwiazda et al[7] measured the accommodative stimulus response curves (ASRCs) under monocular viewing conditions in the emmetropes (those with little or no refractive errors) and early-onset myopic children (children who are myopic before the age of 15) aged between 5 and 17 years. The methods used were decreasing distance series (DDS), negative (NLS) and positive lens series (PLS). Gwiazda and co-workers found that both emmetropes and early-onset myopic children accommodated accurately to real targets at far distances and showed a typical lag of accommodation when presented

[1] School of Chemical & Life Sciences
[3] Singapore Polytechnic Optometry Centre
Singapore Polytechnic, Singapore
[2] Private Practice, Singapore
Address for Reprints: Yeo Chwee Hong (Anna), School of Chemical & Life Sciences, Singapore Polytechnic, 500 Dover Road, Singapore 139651.
Email: YeoCwHng@sp.edu.sg

with near targets. They also noticed accommodative differences between myopic and emmetropic children at 2 of the closest distances when evaluated using the DDS and NLS methods. Abbott et al[6] replicated Gwiazda et al's study in myopic adults and found that the accommodation responses of emmetropes, early-onset myopes and late-onset myopes (the appearance of myopia after age 15) were not significantly different from one another, yet the responses of progressing myopes differed from those of stable myopes and emmetropes. They also found NLS to be a better method of detecting accommodative inaccuracies between emmetropes and myopes.

We aimed to compare the ASRCs of emmetropes and myopes using the methods of DDS, PLS and NLS, and also compare the curves of progressing myopes and non-progressing myopes. Progression was defined as an increase in myopia by 0.50 D or more in the prior 2 years. To our knowledge, there has been no other study on the differences in the accommodative responses between myopes and emmetropes in a predominantly Chinese population. We measured the ASRCs under binocular viewing condition so as to keep the testing condition as similar to real-life seeing conditions as possible.

Materials and Methods

Subjects

Forty-six Chinese and 4 Malay students from a tertiary institution in Singapore were recruited. The age-matched subjects were between the ages of 16 and 23 years (mean, 18.6 ± 1.2), (comprising 41 females and 9 males). Subjects were required to complete a simple questionnaire at the start of the study, giving details of their personal ocular and refractive histories. A total of 17 emmetropes (refractive errors of between -0.25 D and +0.75 D) took part in the study. Among the myopic subjects, 22 were classified as "non-progressing" myopes (with <0.50 D change in prescriptions over 2 years) and 11 were termed "progressing" myopes (with >0.50 D change in their prescriptions over 2 years). The classification of the subjects is summarised in Table 1. All subjects were free from ocular diseases and had no anisometropia (defined as ≥1.00 D difference in spherical equivalent refractive powers between the 2 eyes), less than 0.50 DC astigmatism in either eye, a visual acuity of at least 6/6 on the Snellen chart and minimum monocular amplitude of accommodation of 10 dioptres.

ASRC Measurements

Subjective refraction for each subject was done in order to achieve the best acuity, and the spectacle prescriptions were then used to determine the contact lens powers required for the subject. Contact lenses (of the daily disposable modality and ultra-thin for the comfort of the study subjects) were fitted to subjects prior to the measurement of accommodative responses. The responses to accommodative stimuli were measured using an "open-view" auto-refractor (Grand Seiko WR-5100K, Japan) that allowed subjects to view real targets binocularly at any distance. The target consisted of a horizontal row of 5 high-contrast 6/9 targets printed on a transparency. The transparency was placed in front of a light box, giving a target luminance of 88.7 cdm^{-2} at 4 m and 8.5 cdm^{-2} at 0.25 m. These luminance levels were used to maintain pupil size above the minimum recommended size of ≥2.3 mm.[11] The fixation target was positioned along the subject's line of sight and the auto-refractor was aligned with the corneal reflex. Subjects were instructed to keep the target as clear as possible and to inform the examiner if this was unachievable. For each accommodative demand, 10 measurements were taken with the auto-refractor.

Accommodative responses of subjects were measured using 3 methods:

i. Decreasing distance series (DDS)

Targets were viewed at 5 decreasing distances: 4 m, 1 m, 0.5 m, 0.33 m and 0.25 m. The angular size of the letters was kept constant over these distances.

ii. Positive lens series (PLS)

Subjects viewed through positive lenses of decreasing power in 1 D steps. A +4.00 D lens was first inserted into the trial frame. Instructions were given to the subject to focus at the target at 0.25 m in front. The trial frame was adjusted whenever reflections from the lens hindered the measurement during the study. A total of 10 measurements were taken. This was also done for the other demands of +3.00 D, +2.00 D, +1.00 D and 0 D. The letter chart was not adjusted to account for spectacle lens magnification.

iii. Negative lens series (NLS)

In this method, a similar procedure to PLS was carried out, but using negative lenses of increasing power in 1 D steps, starting from 0 D. The subjects would then focus at the 4-m target throughout this procedure. Ten measurements were again taken for accommodative demands of -1.00 D, -2.00 D, -3.00 D and -4.00 D. The letter chart was not adjusted to account for the minification effect induced by the spectacle lenses.

Invalid readings characterised by large cylindrical components (over 0.75 DC), or error displayed by the instrument due to blinking motions or fixation losses, were discarded. Only right eye data were used for analysis, and only spherical components of the readings were considered. The following formulae, similar to those previously employed,[7,12] were used to calculate the accommodative stimulus and responses of the ASRCs so as to account for the presence of the trial lenses placed in front of the eyes for the NLS and PLS methods (which could have affected both

Table 1. Classification of the Subjects Based on Their Ocular Refraction and Myopic Progression Rate

	EM (n = 17)	NM (n = 22)	PM (n = 11)
Age (y)	19.0 ± 1.0	19.8 ± 1.6	19.1 ± 1.1
Ocular refraction (DS)	+0.24 ± 0.30	-2.56 ± 1.27	-3.17 ± 1.61
Progression rate (DS)	NA	-0.01 ± 0.00	-0.75 ± 0.24

EM: emmetropes; NA: not applicable; NM: non-progressing myopes; PM: progressing myopes

the accommodative demand and response of each subject):

Accommodation stimulus (AS) =

$$AS = \cfrac{1}{\cfrac{1}{\cfrac{1}{DLE - DTE} + LENS} - DLE} - RX_{cornea}$$

Accommodation response (AR) =

$$AR = \cfrac{1}{\cfrac{1}{\cfrac{1}{\cfrac{1}{RawAR_{cornea}} + DLE} + LENS} - DLE} - RX_{cornea}$$

where *AS* and *AR* are the corrected accommodation stimulus and response respectively, RX_{cornea} is the refractive error at the corneal plane (as correction), *DLE* is the vertex distance in metres, *DTE* is the distance from the target to the cornea in metres (both *DTE* and *DLE* are positive), *LENS* is the signed dioptric power of the lens in front of the eye and $RawAR_{cornea}$ is the spherical equivalent of the instrument reading calibrated for the corneal plane.

Results

The gradients of accommodative responses measured by the 3 methods for each individual were averaged (Table 2). The gradient was obtained from the value m of a straight line equation, y = mx +c, by plotting the best fit line of the ASRC of each individual using the Microsoft Office Excel programme. Using single-factor ANOVA, there was a significant difference between the response gradients of the 3 test series ($F_{3.06}$ = 44.815, $P = 6.36 \times 10^{-16}$). The ASRC gradients were found to be method dependent. In addition, when the analysis was done for each refractive group, there were significant differences in response gradients of the 3 test series within each refractive group (emmetropes: $F_{3.195}$ = 22.0132, $P = 1.64 \times 10^{-7}$; non-progressing myopes: $F_{3.195}$ = 22.056, $P = 5.49 \times 10^{-8}$; progressing myopes: $F_{3.195}$ = 9.031; P = 0.0008).

Table 2. ASRC Gradients of the Three Refractive Groups

	EM	NM	PM
DDS	0.804 ± 0.109	0.782 ± 0.105	0.799 ± 0.105
PLS	0.271 ± 0.268	0.422 ± 0.291	0.489 ± 0.270
NLS	0.394 ± 0.311	0.287 ± 0.317	0.152 ± 0.547

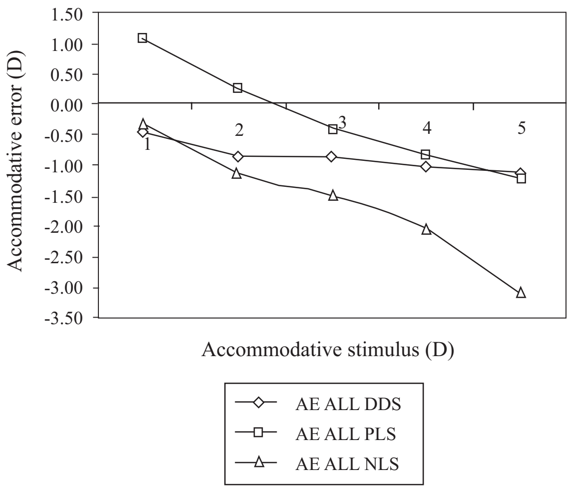
ASRC: accommodative stimulus-response curve; DDS: decreasing distance series; EM: emmetropes; NLS: minus lens series; NM: non-progressing myopes; PLS: positive lens series; PM: progressing myopes

Our results showed that an increase in accommodative stimulus would lead to a corresponding rise in the lag of accommodation for the subjects. This is especially true for the NLS method. When accommodative responses were measured using the PLS method, there was a lead at low demands (values above zero) but as the demands increased, the lag of accommodation (values below zero) became apparent (Fig. 1). In comparison, the DDS and NLS methods showed a consistent lag of accommodation throughout all the accommodative demands. DDS showed the least amount of accommodative errors, followed by PLS and NLS.

For further analysis, the subjects were subdivided into emmetropes (EM), non-progressing myopes (NM) and progressing myopes (PM) groupings based on their refractive errors and progression of myopia. Figures 2, 3 and 4 showed accommodative errors (y-axis) being plotted against accommodative stimulus (x-axis) for the 3 refractive groups. The accommodative errors of each individual were obtained by calculating the difference between accommodative demands and accommodative responses. There was indication of an accommodative lead at low stimulation using PLS (Fig. 3) and an accommodative lag at high stimulation in NLS (Fig. 4). We observed (Fig. 4) that the PM group showed the highest error towards the higher demand compared with the EM and NM groups. Using the single-factor ANOVA, we did not find any significant difference in the response gradients of the 3 refractive groups in each of the 3 methods (DDS: $F_{3.195}$ = 0.234, P = 0.792; PLS: $F_{3.195}$ = 2.375, P = 0.104; NLS: $F_{3.195}$ = 1.394, P = 0.258). Despite the non-significant differences between the gradients of the responses among the 3 refractive groups, there were significant differences in the accommodative responses in the accommodative stimulation of 1 D and 2 D in PLS (Fig. 3) ($F_{9.552}$ = 27.862, P = 0.012) and 3 D and 4 D in NLS (Fig. 4) ($F_{9.552}$ = 22.405, P = 0.016) among the 3 refractive groups.

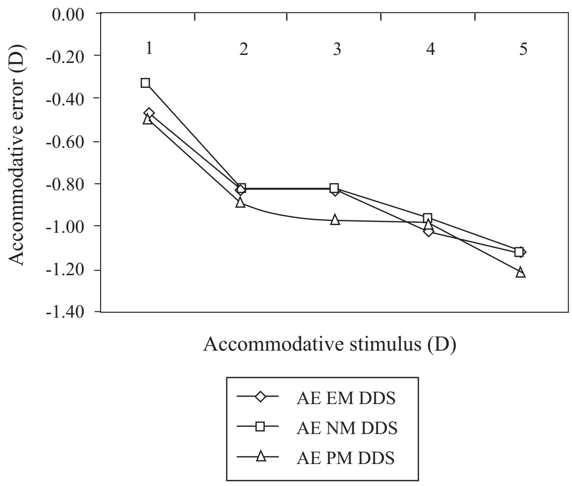
Discussion

The derivation of the ASRC of subjects was method-dependent. In this study, the slope of the ASRC was flatter when determined using the NLS technique and was steeper when the DDS technique was used. There were larger accommodative errors with an increase in stimulus in all techniques. Stimulation using the DDS method produced



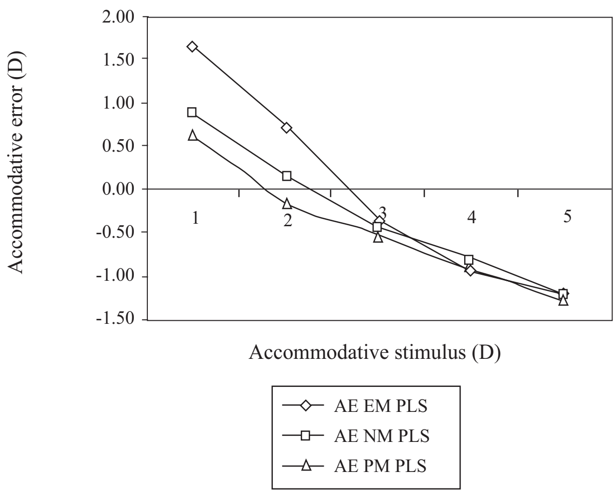
AE: accommodative error; DDS: decreasing distance series; NLS: negative lens series; PLS: plus lens series

Fig. 1. Accommodative lead (values above zero) and lag (values below zero) of the 3 methods of stimulation for all subjects.



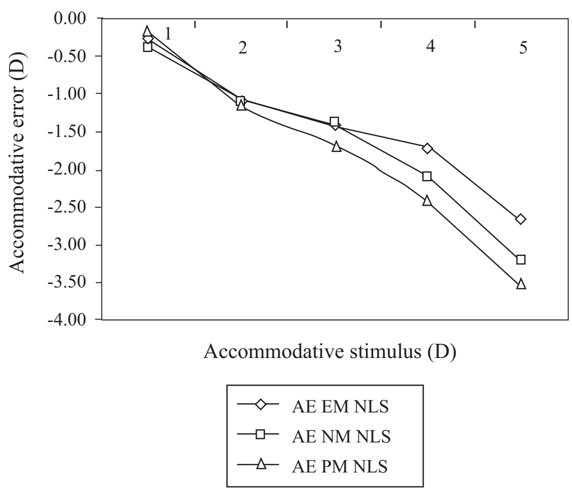
AE: accommodative error: EM: emmetropes; NM: non-progressing myopes; PM: progressing myopes

Fig. 2. Accommodative errors of the 3 refractive groups (DDS).



AE: accommodative error: EM: emmetropes; NM: non-progressing myopes; PM: progressing myopes

Fig. 3. Accommodative errors of the 3 refractive groups (PLS).



AE: accommodative error: EM: emmetropes; NM: non-progressing myopes; PM: progressing myopes

Fig. 4. Accommodative errors of the 3 refractive groups (NLS).

the least accommodative errors and this further confirmed that proximity cues improve the accuracy of accommodative responses.[13] The results also showed that accommodative lags increased in the NLS method. This finding was consistent with those of Gwiazda et al[7] and Abbott et al[6] in that the NLS produced the poorest accommodative response, suggesting negative-induced blur was least effective in producing accommodative responses.

When ASRC gradients of subjects were compared, there were no significant differences between the refractive groups of emmetropes (EM), non-progressing myopes (NM) and progressing myopes (PM). This outcome is consistent with some studies but contrasted with others (Table 3). We believe that the 2 key factors that differentiated our findings from those where statistical significant was found were the number of PM subjects and our measurement of the function by binocular viewing. Abbott et al[6] reported that the greater number of PM subjects in their study was an important factor that led to the significant findings between the myopic and the emmetropic subject groups. The current study had fewer PM subjects than that of Abbott and co-workers. It has also been found[10] that the accommodative lag for each target was significantly smaller in myopes under binocular viewing conditions and that the

Table 3. Comparisons between Current and Previous Studies

	Nakatsuka et al[10] (2003)	**Abbott et al[6] (1998)**	**Gwiazda et al[7] (1993)**	**McBrien and Millodot[8] (1986)**	**Ramsdale[9] (1985)**	**Current study**
Subject no.	n = 43 EM = 15 M = 28	n = 32 EM = 10 SM = 10 PM = 12	n = 64 EM = 48 M = 16	n = 40 EM = 10 EOM = 10 LOM = 10 H = 10	n = 40 EM = 15 M = 15 H = 10	n = 50 EM = 17 NM = 22 PM = 11
Age of subject (y)	Mean 26.9 ± 5.3	Mean 24 ± 4	Mean 11.7	Age range 18-23	Age range 18-34	Mean 18.6 ± 1.2
Methods	Monocular and binocular viewing DDS	Monocular viewing DDS PLS NLS	Monocular viewing DDS (n = 33) PLS (n = 29) NLS (n = 64)	Binocular viewing DDS	Binocular viewing DDS	Binocular viewing DDS PLS NLS
Outcomes of the gradients of ASRC	No significant difference between EM and M in binocular viewing	Significant difference in EM, SM and PM; but no significant difference in EM, EOM and LOM	Significant difference between EM and M in NLS and DDS, but not in PLS	Statistically significant at 4DS and 5DS accommodative demand	No significant difference between EM, M and H	No significant difference between EM, NM and PM
Other important outcomes	EM showed significant accommodative lag than M in monocular viewing	Response gradients were shallower in M, which showed higher accommodative error	Response gradients were shallower in M, which showed higher accommodative error	M showed increased lag at high accommodative demand	Weak correlation between ametropia and accommodative response	Significant difference in accommodative response at high accommodative demand; PM showed highest accommodative error, followed by NM and EM

DDS: decreasing distance series
EM: emmetrope
EOM: early onset myope
H: hyperope
LOM: late onset myope
M: myope
n: number
NLS: negative lens series
NM: non-progressing
PM: progressing myope
PLS: plus lens series
SM: stable myope

mean slopes of ASRC function for early-onset myopes did not differ significantly.[10] These findings may help to explain the results of the current study.

The observation that myopes accommodate less to near targets than emmetropes do reflect a reduced blur-induced accommodation in myopes.[7] When the ability of myopic and emmetropic individuals in detecting the presence of blur was compared, Abraham-Cohen et al[14] found that the emmetropic subjects were able to detect the presence of blur significantly earlier than the myopes. An equally important consideration, accommodative error (AE) for optimum viewing should fall within the depth-of-focus of each individual, typically ±0.30 D for clear retinal image.[15] A lag of accommodation occurring during near work activities should not exceed this, or else the retinal defocus will result in blurry images. An over-correction of 1.00 D at spectacle plane resulted in an accommodative lag of 1.11 D in this study. This amount of lag was theoretically sufficient to induce retinal defocus and may act as a precursor to axial elongation of the eyeball. This inability to accommodate accurately may play a role in the progression of myopia in some vulnerable subjects, though we have yet to establish this link.

Accommodative lags found in the current study were generally greater than in 2 other similar studies (Table 4).[6,7] Do the higher accommodative lags found in our subjects indicate that Asians, in particularly the Chinese, are more vulnerable to myopia development and its progression when compared with non-Asians?[6] Like the noticeable difference in the prevalence rates of angle closure glaucoma between Asian and Caucasian populations,[16,17] would the accommodative responses and lags of these populations be different? Further studies on the accommodative responses of the young Asian population would be useful in answering these questions.

It is important to ensure that myopic children obtain clear vision at both far and near distances by giving them correct prescriptions. Over-correcting children may increase their accommodative lag, leading to a situation of hyperopic defocus, and a worsening of their degree of myopia. The hyperopic defocus hypothesis is supported by data from animal studies. Lens induced myopia from elongated axial lengths occurs in animals that have worn negative spectacle lenses in their early life.[18,19] To reduce the hyperopic defocus for children who present with increased lag of accommodation in the clinic, spectacles with either plus lenses, or multi-focal lenses for convenience, can be prescribed for prolonged near work. This would be the recommended approach for myopic children diagnosed with a large lag of accommodation and large esophorias, since children with large esophoria at near tend to have higher lags of accommodation when they try to relax the convergence which drives the accommodation.[20,21] Indeed, multi-focal lenses have been found to slow down the progression of myopia in this group of near-esophoric children.[22-25]

Conclusion

There were differences in the gradients of the ASRCs, as measured using the 3 methods of accommodative stimulation. There was no significant difference in the gradients of ASRC among emmetropes, progressing and non-progressing myopes. The smaller subject sample in PM was thought to be the cause of the negative finding in the present study. However, significant differences were found in the accommodative responses at 1 D and 2 D

Table 4. Accommodative Errors of the Three Refractive Groups Using the NLS Method

*Abbott et al[6] (1998)	**AS**	**0.25**	**1.20**	**2.20**	**3.20**	**4.00**
	AE for EM	+0.55	+0.30	+0.10	-0.20	0
	AE for SM	+0.85	+0.35	+0.15	-0.10	-0.10
	AE for PM	+0.55	+0.20	-0.10	-0.60	-0.65
*Gwiazda et al[7] (1993)	**AS**	**0.0**	**1.0**	**2.0**	**3.0**	**3.5**
	AE for Child EM	+0.05	-0.50	-0.80	-1.45	-1.60
	AE for Child M	+0.05	-0.80	-1.45	-2.25	-2.85
Current Study	**AS**	**0.25**	**1.23**	**2.19**	**3.12**	**4.03**
	AE for EM	-0.26	-1.10	-1.45	-1.76	-2.69
	AE for NM	-0.41	-1.10	-1.39	-2.09	-3.21
	AE for PM	-0.81	-1.16	-1.69	-2.42	-3.51

+ indicate accommodative leads; - indicate accommodative lags; AE: accommodative error; AS: accommodative stimulus; EM: emmetropes; M: myopes; NLS: negative lens series; NM: non-progressing myopes; PM: progressing myopes; SM: stable myopes

* Values estimated from Abbott et al (1998)[6] in a mainly Caucasian population

stimulated by the PLS method, and at 3 D and 4 D by the NLS method. The accommodative lags measured by the NLS method in the present study were greater than those obtained in other studies done on predominantly Caucasian subjects. Further studies are required to look into the vulnerability of myopia development and the higher lag of accommodation in the predominantly Chinese population.

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