

Effect of Text Type on Near Work–Induced Contrast Adaptation in Myopic and Emmetropic Young Adults

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PURPOSE. Contrast adaptation has been speculated to be an error signal for emmetropization. Myopic children exhibit higher contrast adaptation than emmetropic children. This study aimed to determine whether contrast adaptation varies with the type of text viewed by emmetropic and myopic young adults.

METHODS. Baseline contrast sensitivity was determined in 25 emmetropic and 25 spectacle-corrected myopic young adults for 0.5, 1.2, 2.7, 4.4, and 6.2 cycles per degree (cpd) horizontal sine wave gratings. The adults spent periods looking at a 6.2 cpd high-contrast horizontal grating and reading lines of English and Chinese text (these texts comprised 1.2 cpd row and 6 cpd stroke frequencies). The effects of these near tasks on contrast sensitivity were determined, with decreases in sensitivity indicating contrast adaptation.

RESULTS. Contrast adaptation was affected by the near task ($F_{2,672} = 43.0$; $P < 0.001$). Adaptation was greater for the grating task (0.13 ± 0.17 log unit, averaged across all frequencies) than reading tasks, but there was no significant difference between the two reading tasks (English 0.05 ± 0.13 log unit versus Chinese 0.04 ± 0.13 log unit). The myopic group showed significantly greater adaptation (by 0.04, 0.04, and 0.05 log units for English, Chinese, and grating tasks, respectively) than the emmetropic group ($F_{1,48} = 5.0$; $P = 0.03$).

CONCLUSIONS. In young adults, reading Chinese text induced similar contrast adaptation as reading English text. Myopes exhibited greater contrast adaptation than emmetropes. Contrast adaptation, independent of text type, might be associated with myopia development. (*Invest Ophthalmol Vis Sci.* 2013;54:1478–1483) DOI:10.1167/iovs.12-11496

Myopia prevalence is high in developed East Asian countries such as Hong Kong, Taiwan, and Singapore.^{1–5} In the past, the primary cause of myopia was thought to involve genetics (reviewed in Feldkamper and Schaeffel⁶), and there is a well-known tendency for familial patterns of inheritance of myopia.⁷ However, the recent rapid increase in the prevalence of myopia in developed countries with

intensive and competitive education systems indicates that there is a very strong environmental impact on myopia development. Epidemiological correlation-based studies suggest that lengthy periods spent performing near work^{8,9} (at close distances and young ages) and lack of outdoor activities¹⁰ are likely to contribute to the high myopia levels. Since the increased prevalence is occurring in countries with predominantly Chinese populations, there is a possibility that Chinese text may play a role in near work–induced myopia development.

Written Chinese is a logographic system,¹¹ in which the characters of the basic writing unit possess many strokes packed into a square shape without spaces to separate the words (i.e., strokes are closer). The text is formed by strings of equally spaced box-like characters. Chinese readers depend on lexical knowledge to segment characters into words.¹² Unlike the use of phonemes in spoken English, Chinese character pronunciation is defined at the syllable level and must be learned through rote memorization of the association of visual character form and sound, occasionally with the aid of subcharacter units that are themselves real characters. These characteristics suggest that the processing and neurocognitive mechanisms underlying Chinese logographic reading may differ from those underlying alphabetic word reading.¹³ There are more than 5000 Chinese characters¹⁴ in contrast to 26 letters in English, and the information density in Chinese characters is much higher than in English letters. These differences may make it harder to resolve Chinese words than English words.

In a previous study, we found that contrast adaptation occurred in children after both viewing horizontal gratings and reading English text.¹⁵ The adaptation induced by reading was significantly higher, by 0.11 log unit at 4.4 cycles per degree (cpd), in myopic children than in emmetropic children. Our findings¹⁵ supported the proposal that contrast adaptation could result in perceived retinal image defocus, thus inducing a retinal error signal driving axial elongation.^{16,17}

Reading is associated with greater contrast adaptation in myopic children than emmetropic children,¹⁵ but the influence of different types of text is not known. Furthermore, since the prevalence of myopia is high among Chinese children⁵ and in countries where Chinese is taught in schools from a young age, we hypothesize that the complex Chinese text induces greater contrast adaptation than English text. Accordingly, we measured contrast adaptation following periods of reading both English and Chinese texts in both emmetropic and myopic young adults.

METHODS

Participants

Participants were either optometry students or patients of the Singapore Polytechnic Optometry Centre. The research followed the tenets of the Declaration of Helsinki and was approved by both the

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Singapore Eye Research Institute Institutional Review Board and the Queensland University of Technology, Human Research Ethics committee. Prior to participation, informed written consent was obtained from the participants or a parent or guardian if a participant was less than 21 years old.

Fifty young adults, including 32 females and 18 males, aged 16 to 25 years and comprising 25 emmetropes (spherical equivalent refraction [SER] +0.75 to -0.25 diopters [D], mean age 18.6 ± 1.0 years) and 25 myopes (SER ≤ -0.50 D, mean age 18.3 ± 1.3 years) were recruited. The mean SER (based on subjective refraction) and axial length measured with the IOLMaster (Carl Zeiss Meditec, Inc., Jena, Germany) of the emmetropes were $+0.11 \pm 0.31$ D and 23.4 ± 0.9 mm, respectively, and those of the myopes were -3.01 ± 1.30 D and 24.9 ± 0.9 mm. The IOLMaster (Carl Zeiss Meditec, Inc.) gives similar axial lengths to those obtained by ultrasonography.^{18,19}

Inclusion criteria were at least 6/6 monocular visual acuity and contrast sensitivity (Pelli-Robson CS) better than 1.65, cylinder ≤ 0.75 DC, -6.0 D \leq SER $\leq +0.75$ D and anisometropia ≤ 1.0 D, no ocular disease and no strabismus, and ability to read both Chinese and English texts. All the myopes were stable myopes whose myopia had not progressed more than 0.25 D per year during the past 2 years.²⁰ Myopes were full-time prescription wearers and included three contact lens wearers. Contrast sensitivity testing was performed on the right eye unless this eye failed the inclusion criteria and the left eye passed; this occurred for four participants for whom the right eye had astigmatism > 0.75 DC.

Procedure

The experimental setup and test procedures have been described in detail previously.¹⁵ Contrast sensitivity was measured using the Metropsis Psychophysical Vision Testing (MPVT; Cambridge Research System, Rochester, UK). The protocol was a two-interval forced choice logarithmic staircase procedure. Mean and standard deviation of contrast sensitivity were determined from the last 8 of 12 staircase reversals.

The adapting stimuli (printed text and contrast grating) were placed in a holder 40 cm from the participant while the contrast testing monitor was 1 m from the participant. The participant turned his or her body through 90° to view either the adapting stimuli or the monitor. All participants were corrected using a trial frame and trial lenses. The small increases in effective spatial frequencies provided by spectacle lenses, 8% for the maximum lens power of -5.75 D at 15-mm distance between pupil and lens back vertex distance, would have been compensated by increases in axial length of myopes relative to those of emmetropes. The participants adapted with both eyes and then turned to the computer screen. During testing an occluder was fixed at the chin and head rest in front of the non-tested eye. All participants had practice sessions until they reported confidence in their ability to perform the test.

Baseline contrast sensitivity was determined for 0.5, 1.2, 2.7, 4.4, and 6.2 cpd, either in ascending or descending spatial frequency order; this was randomized between participants and repeat runs (three trials were conducted and data averaged for each spatial frequency) followed the same randomized order. The angles subtended by the adapting stimuli were 35° horizontal and 27° vertically and the testing Gabor size was 2.4° (full width at half maximum).

Three adaptation tasks were used: silent reading of English text and Chinese text and viewing of a 6.2 cpd, 92% contrast (Michelson formula), sine-wave horizontal grating. The reading texts consisted of high-contrast (92%) hard-copy print of children's stories; the English text was in 12 point Times New Roman font with a line spacing of 17.5 points on A4 landscape paper, and the Chinese text was in SimSun 10.5 with a spacing of 17.5 points. The grating was printed on white A4 landscape paper and the participant fixated on a small cross at the grating center.

The row and stroke frequencies of the texts were 1.2 and 6.04 cpd, respectively. To determine row frequency, the text was assumed to

form the black bars of a grating and the spaces between the texts formed the white bar of the grating. The stroke frequency was calculated according to Majaj et al.²¹ A horizontal line was drawn across the letters of a word and the vertical strokes of the letters that crossed the horizontal line were counted. Stroke frequency was obtained by averaging the number of strokes crossing the horizontal midline for all the letters, divided by the average letter width in degrees. The first two rows of words of the adapting text stimuli were measured. The MPVT was not able to generate 6.0 cpd, and a spatial frequency of 6.2 cpd was used for the adapting grating task.

Contrast sensitivity measurement for the three adapting conditions was randomized between participants. An adapt-test-re-adapt paradigm (adapt 1 minute, test 30 seconds, and re-adapt 1 minute) was used to ensure stable levels of contrast adaptation were maintained during the testing procedure.²² Participants were given short breaks for each spatial frequency tested within an adaptation task and longer breaks between each adaptation task. Three trials were conducted and data were averaged for each spatial frequency.

Data Analysis

Analysis of variance using the general linear model was used to analyze the data. Log contrast adaptation was the dependent variable. The independent variables were refractive error group nested in participants, spatial frequencies (five), and adaptation tasks (three). The participant factor was randomized so that significant results could be generalized to the larger population. *T*-tests with a Bonferroni correction were used for post hoc pair-wise comparisons of the three adapting conditions (corrected $P < 0.017$). Presented data are mean \pm SD unless stated otherwise.

RESULTS

Figure 1 shows mean log contrast sensitivities at baseline, during reading of text and during viewing of a horizontal grating for (1) all participants, (2) emmetropic young adults, and (3) myopic young adults. Baseline contrast sensitivity was not affected by sex ($F_{1,48} = 2.7$, $P = 0.11$), age ($F_{6,43} = 0.7$, $P = 0.65$), or refractive error group ($F_{1,48} = 2.0$, $P = 0.16$).

The Table and Figure 2 show the means and standard deviations of contrast adaptation during reading and during viewing the horizontal grating. Contrast adaptation was affected by the near task ($F_{2,672} = 43.0$, $P < 0.001$), such that adaptation was significantly greater for the grating task (0.13 ± 0.17 log unit) than for reading tasks and there was no significant difference between the two reading tasks (English 0.05 ± 0.13 log unit versus Chinese 0.04 ± 0.13 log unit).

Adaptation was significantly different across the range of spatial frequencies tested ($F_{4,672} = 7.5$, $P < 0.01$). There was a significant interaction between task and spatial frequency ($F_{8,672} = 19.3$, $P < 0.01$), with adaptation significantly greater for gratings than for texts at 4.4 and 6.2 cpd (Fig. 2).

Post hoc tests showed significant adaptation ($P < 0.001$) for the grating task for both emmetropes (0.11 ± 0.15 log units) and myopes (0.15 ± 0.18 log unit). Post hoc tests also showed significant adaptation for both English text (0.07 ± 0.12 log unit; $P < 0.001$) and Chinese text (0.06 ± 0.13 log unit; $P < 0.001$) in myopes, but these were not observed in emmetropes (0.03 ± 0.13 log unit English [$P = 0.62$], 0.02 ± 0.13 log unit Chinese [$P = 1.0$]).

When data were pooled across spatial frequencies and tasks, the myopes showed significantly greater adaptation than the emmetropes (0.09 ± 0.13 vs. 0.05 ± 0.13 log unit, $F_{1,48} = 5.0$; $P = 0.03$). The interaction between refractive error group and adaptation task was not significant ($F_{2,672} = 0.1$, $P = 0.95$), and neither was the interaction between refractive error group and spatial frequency ($F_{4,672} = 0.2$, $P = 0.92$).

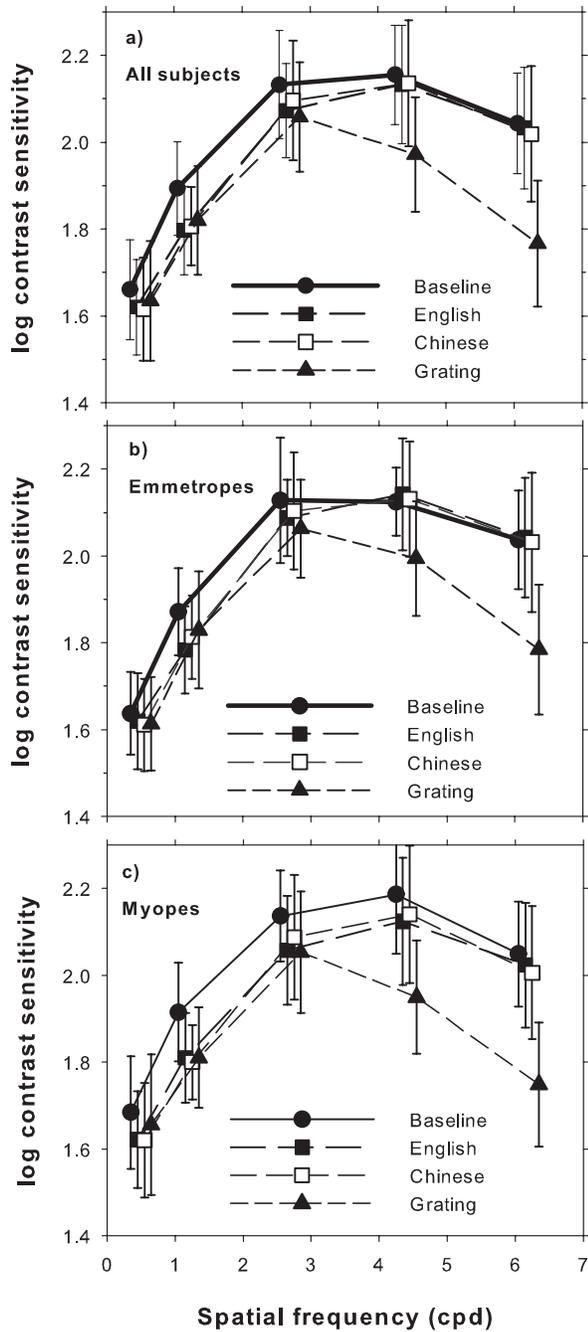


FIGURE 1. Mean \pm SD log contrast sensitivities of (a) all participants, (b) emmetropes, and (c) myopes at baseline and during reading of English text, reading of Chinese text, and viewing a horizontal sine wave grating. To improve clarity, the plots are displaced horizontally relative to each other.

DISCUSSION

Reading either English or Chinese text induced a similar amount of contrast adaptation, and in both cases this was less than viewing a horizontal sine wave grating. Myopic young adults showed significantly greater contrast adaptation than emmetropic young adults, by 0.04 log unit (9%). The processing of different text types, the calculation of stroke frequencies of texts, and the effect of contrast adaptation and refractive errors are discussed in following text.

TABLE. Contrast Adaptation during Reading and Viewing the Horizontal Grating in Myopic and Emmetropic Young Adults

Adaptation Task	English Text					Chinese Text					Horizontal Grating				
	Spatial Frequency	0.5	1.2	2.7	4.4	6.2	1.2	0.5	2.7	4.4	6.2	1.2	2.7	4.4	6.2
Contrast adaptation, log unit	All	0.040 \pm 0.119	0.096 \pm 0.117*	0.060 \pm 0.103	0.022 \pm 0.131	0.010 \pm 0.153	0.045 \pm 0.105	0.020 \pm 0.132	0.036 \pm 0.135	0.020 \pm 0.132	0.024 \pm 0.152	0.073 \pm 0.148	0.074 \pm 0.138	0.184 \pm 0.143*	0.277 \pm 0.161*
	E	0.017 \pm 0.116	0.088 \pm 0.136	0.040 \pm 0.115	-0.018 \pm 0.116	-0.005 \pm 0.158	0.026 \pm 0.075	-0.006 \pm 0.098	0.024 \pm 0.158	0.005 \pm 0.166	0.024 \pm 0.090	0.042 \pm 0.152	0.065 \pm 0.148	0.131 \pm 0.110*	0.253 \pm 0.145*
	M	0.062 \pm 0.119	0.105 \pm 0.097*	0.079 \pm 0.088	0.062 \pm 0.136	0.025 \pm 0.150	0.064 \pm 0.127	0.046 \pm 0.156	0.049 \pm 0.109	0.043 \pm 0.138	0.028 \pm 0.134	0.105 \pm 0.140	0.084 \pm 0.130	0.237 \pm 0.154*	0.301 \pm 0.175*

The data are mean \pm SD. All, all participants; E, emmetropes; M, myopes. * Adaptation significant ($P < 0.05$).

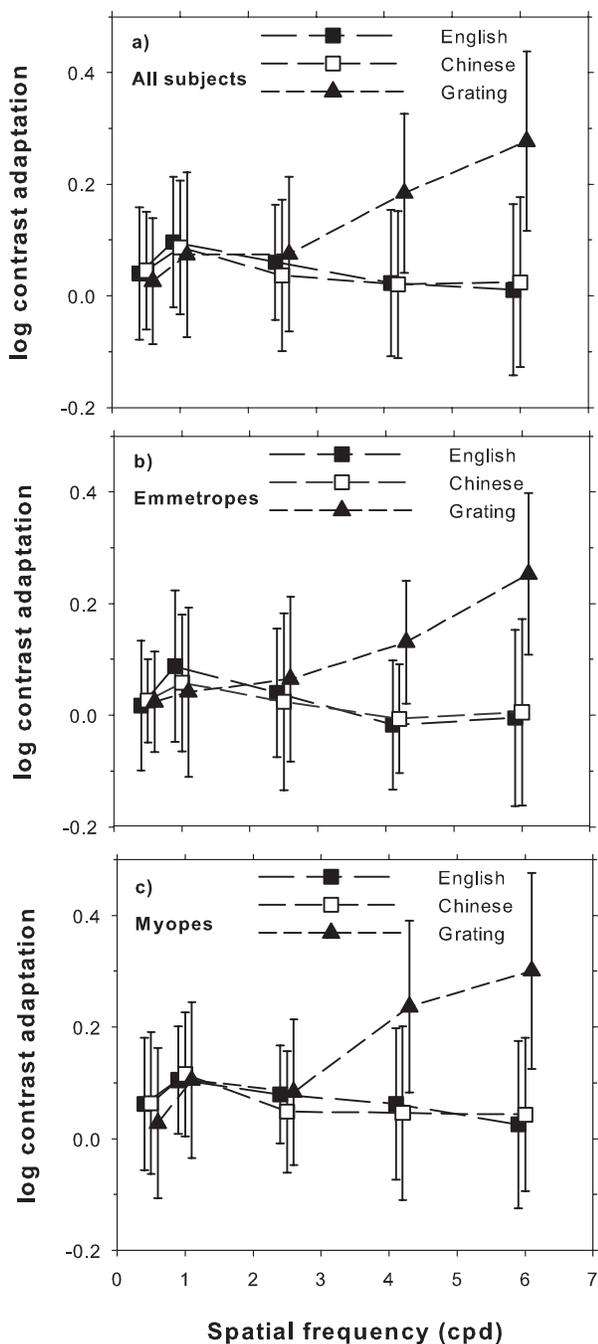


FIGURE 2. Mean ± SD log contrast adaptations of (a) all participants, (b) emmetropes, and (c) myopes at baseline and during reading of English text, reading of Chinese text, and viewing a horizontal sine wave grating. To improve clarity, the plots are displaced horizontally relative to each other.

Chinese versus English Text

The findings do not support the hypothesis posed in the introduction that adaptation might be greater for Chinese compared to English text. Although many differences between the two types of texts such as the logographic system of Chinese text, the pronunciation and the processing of the Chinese text are different from the English text; these are mostly cognitive differences. The reason for the similarity in adaptation could be due to the similar stroke and row frequencies of both texts, since contrast adaptation is mostly

dependent on spatial frequency and contrast of the adapting stimuli.^{23,24}

Simplified Chinese was chosen because it is the most widely read text in Singapore and China. Simplified Chinese characters have fewer strokes than traditional Chinese characters. Although the font is smaller than English (10.5 SimSun versus 12 Times New Roman), the character widths are larger than English letters, thus leading to a smaller than expected calculated stroke frequency, since the stroke frequency is equal to the average number of strokes divided by the average width of each letter. The proposed calculation of the stroke frequency may not be the best way to determine the center frequency of the characters because the strokes are orientation specific. A suggestion is to include all the strokes in the calculation of Chinese characters, regardless of the orientation (i.e., horizontal, vertical, or oblique). Using this method of calculation, the Chinese characters are 14 strokes/deg, which is very different from the 6.2 strokes/deg calculated using the method of Majaj et al.²¹ It is thus possible that greater contrast adaptation would have occurred for Chinese compared with English text at this higher spatial frequency. Since we did not test higher than 6.2 cpd, our study does not address this.

Myopes versus Emmetropes

Since we observed higher contrast adaptation in myopes than in emmetropes, for both young adults and children¹⁵ previously, we believe that contrast adaptation during reading has a role in myopia development. The adaptation was small, but as has been discussed previously,¹⁵ it need not be high to cause myopia. Contrast adaptation induced by prolonged reading may induce a reduction in the perceived retinal image quality that is similar to that of form deprivation. In neurophysiological terms, contrast adaptation may result in either desensitization or neural fatigue of the visual system.²⁵⁻²⁷ The reduced retinal activity (analogous to visual deprivation) could become an error signal for eye growth processes. In chicks, 2 to 3 minutes of exposure to defocus is sufficient to induce changes in eye growth,^{28,29} so reading for more than an hour (which is not uncommon, with a previous study on Singaporean children reporting that some children read for up to 3 hours before bedtime³⁰) could be very detrimental.

Adults versus Children

The findings of this study are consistent with those of our previous study performed on children.¹⁵ Similar to the study on children,¹⁵ the greatest difference in adaptation between emmetropic and myopic young adults occurred at 4.4 cpd, but the adaptation was lower in magnitude in young adults than in children (0.08 log unit vs. 0.19 log unit). The difference is indicative of greater neural plasticity in children than young adults (reviewed by Huttenlocher³¹). For example, there is decline, commencing in late adolescence, in the number of labile synapses.

Limitations of the Study

One of the limitations of the study was the setup of the reading and testing tasks. When the subject swiveled from the adaptation task to the test grating, there was a time loss of 1 to 2 seconds and thus an inevitable loss of adaptation. This could be overcome if the adapting task could be projected on the same computer as the test stimuli without disrupting the contrast sensitivity testing. Another limitation was that the time spent reading was only 5 minutes in duration, chosen so

that the participants would not lose attention; greater adaptation may occur following longer reading periods.^{22,32-35}

Future Studies

Future studies could consider the effect of adaptation at peripheral retinal locations since studies have found form deprivation in the peripheral retina can influence the development of refractive error in nonhuman primates.³⁶ Homeostatic growth signals from the relatively hyperopic periphery of a myopic eye may direct the eye to grow; the spatial summation signals from the much bigger area of peripheral than central retina could dominate the emmetropization process even though the density of the neurons is greater in the central retina.³⁷ As such, investigation of contrast adaptation at the retinal periphery may provide some vital information on its role in myopia development. In this case, lower spatial frequencies should be investigated because the peak of the contrast sensitivity function is displaced toward lower spatial frequencies as eccentricity is increased.³⁸ A recent study found that neural adaptation occurs in the parafovea as well as the fovea.³⁹ Hence, further investigation of the contrast adaptation at the parafovea or peripheral retina may provide insights to the importance of neural adaptation in myopia development.

CONCLUSIONS

For young adults, reading Chinese text induced similar contrast adaptation as reading English text. Myopic young adults exhibited greater contrast adaptation than emmetropic young adults.

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