Near Work–Induced Contrast Adaptation in Emmetropic and Myopic Children

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Purpose. Contrast adaptation may induce an error signal for emmetropization. This research aims to determine whether reading causes contrast adaptation in children and, if so, to determine whether myopes exhibit greater contrast adaptation than emmetropes.

Methods. Baseline contrast sensitivity was determined in 34 emmetropic and 34 spectacle-corrected myopic children for 0.5, 1.2, 2.7, 4.4, and 6.2 cycles per degree (cpd) horizontal sine-wave gratings. Effects of near tasks on contrast sensitivity were determined during periods spent looking at a 6.2 cpd horizontal grating and during periods spent reading lines of English text, with 1.2 cpd row frequency and 6 cpd stroke frequency.

Results. Both emmetropic and myopic groups (mean ± SD; age, 10.3 ± 1.4 years) showed reduced contrast sensitivity during both near tasks, with greatest overall adaptation at 6.2 cpd. Adaptation induced by viewing the grating (0.15 ± 0.17 log unit [40%]; range, 0.07–0.27 log unit) was significantly greater than adaptation induced by reading text (0.11 ± 0.18 log unit [29%], 0.08–0.16 log unit) ($F_{1,594} = 10.7$; $P = 0.001$). Myopic children showed significantly greater adaptation across the tasks (0.15 ± 0.18 log unit [42%]) than emmetropic children (0.10 ± 0.16 log unit [26%]) ($F_{1,66} = 7.30$; $P = 0.009$), with the greatest difference occurring at 4.4 cpd (mean, 0.11 log unit [30%]).

Conclusions. Grating and reading tasks induced contrast adaptation; viewing horizontal gratings induced greater adaptation than reading, and myopes exhibited greater adaptation than emmetropes. Contrast adaptation effects may underlie findings of prolonged near work being associated with myopia. However, our research does not show whether this is consequential or causal. (*Invest Ophthalmol Vis Sci.* 2012; 53:3441–3448) DOI:10.1167/iovs.11-8959

There has been an increasing prevalence of myopia amongst young children in East Asian countries such as Japan,[1] Hong Kong,[2] Taiwan,[3] and Singapore.[4] This suggests early lifestyle factors may have a large impact on early myopia development. The rapidity of the increase in myopia rates is unlikely to be caused by gene changes and therefore has been attributed to increases in reading activity and other environmental factors (reviewed in Morgan and Rose[5]). A highly competitive education system and long periods spent performing near work are the environmental factors reported to be most strongly linked to myopia development in these countries.[6,7] The association between near work and myopia has been reported in several studies,[7–9] but how near work causes and/or exacerbates myopia development generally, and more particularly in children, is poorly understood (reviewed in Rosenfield and Gilmartin[8]). It is also possible that low participation in outdoor activities has contributed to the high prevalence of myopia in these countries, since outdoor activity has been suggested to be protective against myopia.[10]

There is evidence that the eye growth process is guided by a feedback system involving the visual signal quality (reviewed in Wildsoet[11] and Wallman and Winawer[12]). A good quality visual signal, made up of a variety of spatial frequencies and contrasts,[13–15] is critical for normal visual development. Eyes experiencing poor retinal images induced by diffusers or minus lenses have excessive growth and become myopic.[12,15–17] Reading involves looking at high-contrast text[12] at near for prolonged periods of time. Spatial frequency and contrast content may be limited, and this may be exacerbated by contrast and spatial adaptations.[12,18]

Contrast sensitivity is decreased in response to prolonged viewing of high-contrast gratings[18–20] as a result of contrast adaptation. Adaptation is strongest when the adapting grating has the same spatial frequency and orientation as the test grating.[18,21] It was originally suggested that contrast adaptation saturates after as little as 40 seconds,[18] but Magnussen and Greenlee[22] found contrast adaptation increased for 30 to 60 minutes. Recovery from adaptation mirrors the adaptation dynamics, in that longer adaptation times have longer recovery times.[22–24]

Reading usually requires intense viewing of high-contrast text for several minutes to hours. The text could produce contrast adaptation.[25] It is likely that contrast adaptation reduces contrast sensitivity to spatial frequencies similar to those created by the row frequency or stroke frequency of the text. If this phenomenon is associated with the development of myopia, contrast adaptation may be greater in myopes than in emmetropes. Accordingly, we hypothesize that myopic children will have greater contrast adaptation than emmetropic children. One aim of this study was to determine whether reading causes contrast adaptation in children, and if so, to test the hypothesis that myopes exhibit greater contrast adaptation than emmetropes. A second aim was to determine whether contrast adaptation differed for text and gratings.

Methods

Participants

Participants were recruited from the Singapore Polytechnic Optometry Centre of the Singapore Polytechnic and its satellite clinic in the West

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Table 1. Number of Children in the Emmetropic and Myopic Groups—Age, Ethnicity, and Sex

Mean SER ± SD (D)	Emmetropes (34) +0.03 ± 0.13 D	Myopes (34) −2.73 ± 0.18 D	Subtotal	Total
Age (y)				
7 to 8	8	3	11	68
9 to 10	9	9	18	
11 to 12	17	22	39	
Ethnicity				
Chinese	17	19	36	68
Malay	7	10	17	
Indian	10	5	15	
Sex				
Male	17	14	31	68
Female	17	20	37	

Coast Community Centre. The research followed the tenets of the Declaration of Helsinki and was approved by both the Singapore Eye Research Institute Institutional Review Board and the Queensland University of Technology. Informed written consent was obtained from both the child and a parent or guardian prior to participation.

Sixty-eight children aged 7 to 12 years (mean age, 10.3 ± 1.4 years) of Chinese, Malay, and Indian descents were recruited. Participants were classified as either emmetropic (spherical equivalent refraction [SER] +0.75 to –0.25 diopter [D]) or myopic (SER ≤ –0.50 D). There were 34 emmetropes (mean, SER ± SD, +0.03 ± 0.13 D) and 34 myopes (–2.73 ± 1.18 D). Characteristics of both refractive groups are presented in Table 1.

Inclusion criteria were Snellen visual acuity for each eye ≥6/6, monocular Pelli-Robson chart contrast sensitivity for each eye ≥1.65, cylinder for each eye ≤0.75 diopter cylinder (DC), –6.0 ≤ SER ≤ +0.75 D, anisometropia ≤1.00 diopter sphere (DS), and absence of any ocular disease including strabismus. Subjective refraction was performed to measure refractive errors using the technique of maximum plus for best visual acuity. Parents completed a questionnaire on behalf of their children. Questions included past and present ocular history and details of ocular health. Rate of myopia progression was determined based on optometric records or by comparing the subjective refraction with the spectacle prescription and reported age of the spectacles. For 40 children, the subjective refraction at the last visit was compared with that recorded on the clinic record 1 to 2 years earlier. For 28 children, optometric records were not available, and here, the subjective refraction performed was compared with the spectacle prescription, and the parents asked to report when the spectacles had been dispensed. The difference in the refraction data was divided by the time frame between the values in months and multiplied by 24 (to give an estimate of progression over 2 years for classification purposes). The myopes were all progressing myopes according to the criterion that myopia had increased by at least 0.50 D per year during the previous 2 years.[26] All myopic children were full-time spectacle lens wearers. Contrast-sensitivity testing was performed on the right eye unless this eye just failed to meet the inclusion criteria and the left eye met the criteria; this occurred for four right eyes with astigmatism >0.75 D and two right eyes with a Pelli-Robson score of 1.60.

Procedure

Contrast sensitivity was measured using the Metropsis Psychophysical Vision Testing (MPVT, Cambridge Research System, Rochester, UK) in a lighted room. Test stimuli were presented on a high-definition 53-cm ViewSonic Professional Series P225f CRT monitor (ViewSonic International, Singapore, Singapore). The angular size of the stimuli was 17° × 22° at 1 m with a mean luminance of 50 cd/m². The protocol was a two-interval forced choice logarithmic staircase procedure, with different buttons pressed to indicate whether the grating appeared in the first or second interval. Contrast sensitivity and its standard deviation were calculated using the sensitivities at staircase reversal points.

The adapting stimuli and the computer screen of the contrast testing equipment were placed 90° to each other and at 40 cm and 1 m, respectively, from the participant (see Fig. 1). Participants were corrected using a trial frame and ophthalmic lenses. They viewed the

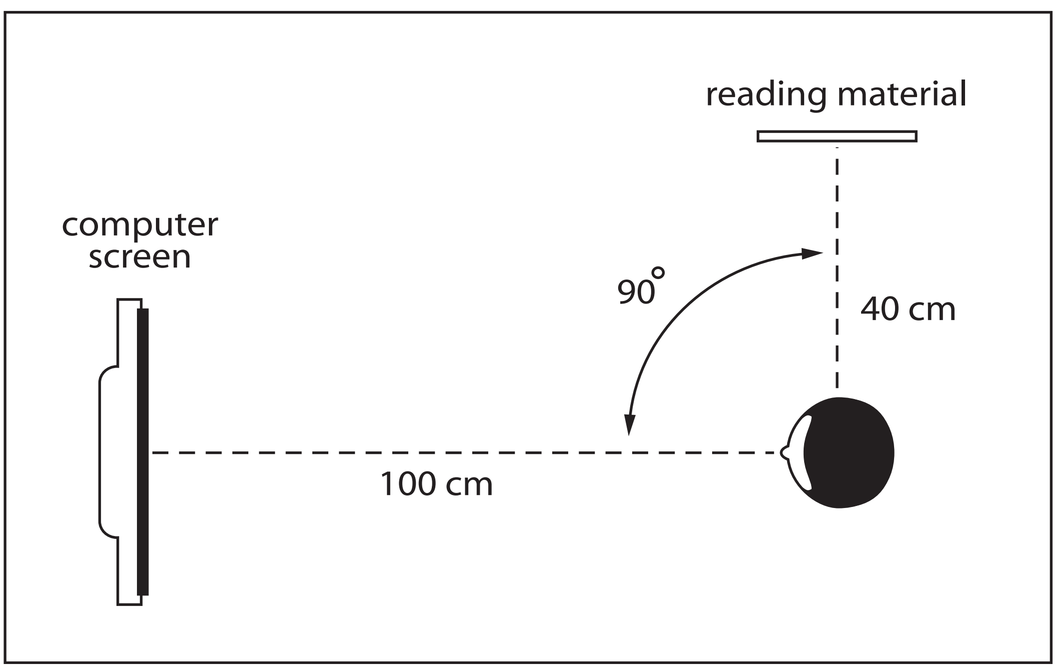

Figure 1. Experimental design. The adaptation task was placed 90° to the test stimuli. Participants viewed the adaptation task for 1 minute and then turned and performed contrast-sensitivity testing for 30 seconds; this cycle was repeated until the contrast threshold was determined.

adapting stimuli with both eyes and then turned to face the computer screen during testing. During contrast-sensitivity testing, a headrest-mounted occluder covered the non-test eye. All the 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 cycles per degree (cpd), testing either in ascending or descending spatial frequency order; this was randomized between participants, and repeat runs followed the same order in the adaptation tasks. Three trials were performed for each spatial frequency during adaptation, and results were averaged. The angular subtenses for adapting stimuli were 35° horizontally and 27° vertically, and the testing Gabor size was set at 2.35° (full width at half maximum) at 1-m distance.

Two adaptation tasks were used: silent reading of high-contrast English text and viewing of a 6.2-cpd, 92%-contrast, sine-wave horizontal grating—both tasks were presented at a 40-cm distance. The reading task consisted of a high-contrast (92%) hard-copy print of children's stories written in English in 12-point Times New Roman font, with a line spacing of 17.5 point on A4 landscape paper. The grating was similarly printed on white A4 landscape paper; participants fixated the grating center.

The row and stroke frequencies of the text were 1.2 cpd 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 text formed the white bars of the grating. The stroke frequency was calculated according to Majaj et al.[27] A horizontal line was drawn across the letters of a word, and the number of vertical strokes of the letters that crossed the horizontal line was 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. As the MPVT was not able to generate 6.0 cpd, a spatial frequency of 6.2 cpd was used for the adapting grating task.

Contrast-sensitivity measurement for the two adapting conditions was randomized between participants. The participant adapted to the task for 1 minute, then turned his or her head to the computer screen for the contrast-threshold measurement, which lasted 30 seconds. This procedure was repeated until three threshold values were obtained for each spatial frequency. The participants took approximately 4 hours to complete both tasks. The adapt–test–readapt paradigm (adapt 1 minute, test 30 seconds, and readapt 1 minute) was used to ensure that stable levels of contrast adaptation were maintained during the testing procedure.[23] The children were given a lunch break between each adaptation task, and they were given short breaks between each of the spatial frequencies tested within an adaptation task.

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 (two). The participant factor was randomized, so that significant results could be generalized to the larger population. Post-hoc Fisher least significant difference (LSD) and Bonferroni tests were used to assess comparisons when there were more than two levels within a variable.

Results

We conducted a pilot study on a group of 10 children selected randomly from the main test group to look for a possible influence of fatigue on the results. These children performed a second standard contrast-sensitivity test 10 minutes after the entire test procedure was complete. There was no statistical difference between the tests (mean difference, 0.03 ± 0.16 log unit; $F_{1,73} = 0.00$, $P = 0.95$).

To provide an indication of the within-session repeatability of the contrast-sensitivity testing, we calculated the coefficient of variation (i.e., the within-participant standard deviation divided by the mean), for each spatial frequency tested. The average (and standard deviation) of coefficient of variation (COV) for baseline contrast-sensitivity measurements was an acceptable 13%,[28] which showed that the contrast-sensitivity function (CSF) measures were reliable.

Baseline contrast sensitivity was not affected by ethnic background ($F_{2,65} = 1.26$, $P = 0.291$), sex ($F_{1,66} = 0.02$, $P = 0.884$), or refractive error group ($F_{1,66} = 0.05$, $P = 0.829$) but was significantly affected by age ($F_{5,62} = 5.90$, $P < 0.001$). Post-hoc testing showed greater contrast sensitivity in older children, aged 11 and 12 years, than in younger children, aged 7 and 8 years, with the largest mean difference measured between 8- and 12-year-old children (0.19 log unit).

Figure 2 shows the mean log contrast sensitivities at baseline, during reading of text and during viewing of a horizontal grating for all participants (Fig. 2a), emmetropic children (Fig. 2b), and myopic children (Fig. 2c). Twenty-four of 34 (70%) emmetropic and 28 of 34 (82%) myopic children showed contrast adaptation after near tasks. The greatest adaptation overall occurred at 6.2 cpd. Figure 3 shows the corresponding means and standard deviations of contrast adaptation during reading text and viewing the horizontal grating. These values are also presented in Table 2. The mean contrast adaptations at different spatial frequencies, induced by reading text and viewing the horizontal grating, ranged from 0.077 to 0.161 (mean ± SD, 0.11 ± 0.18) and 0.070 to 0.273 (0.15 ± 0.17) log units, respectively. With the Fisher LSD post-hoc test, contrast adaptation was significant at all spatial frequencies for both reading and for viewing the horizontal grating. With the Bonferroni post-hoc test, contrast adaptation was significant at all spatial frequencies except for 0.5 cpd after reading text and for 0.5 and 1.2 cpd after viewing the horizontal grating. The largest contrast adaptation occurred after viewing the horizontal grating when the test spatial frequency was at the adapting spatial frequency of 6.2 cpd (0.27 ± 0.19 log units). Significantly greater adaptation occurred during viewing of the horizontal grating than during reading text (mean difference, 0.037 log units; $F_{1,594} = 10.69$; $P = 0.001$). There was significant interaction between adaptation tasks and spatial frequency ($F_{4,594} = 10.86$; $P < 0.001$), with post-hoc tests showing significant difference in the adaptations for the two tasks at 4.4 and 6.2 cpd only.

Across both tasks, the myopic children showed significantly greater adaptation of 0.15 ± 0.18 log units (mean ± SD) than the emmetropic children (0.10 ± 0.16 log units) ($F_{1,66} = 7.30$; $P = 0.009$). There was no significant interaction between refractive error group and adaptation task ($F_{1,594} = 0.21$; $P = 0.650$). There was no significant interaction between refractive error group and spatial frequency ($F_{4,594} = 0.86$; $P = 0.495$). The largest adaptation difference between emmetropes and myopes occurred at 4.4 cpd (mean 0.11 log unit), and this was significant using the Fisher LSD post-hoc test ($P = 0.014$).

Discussion

Based on the spatial frequency content of the adapting targets and literature,[13,18,27,29] we expected to see contrast adaptation around 6 cpd for the sine-wave grating[18,30] and around either the row (1.2 cpd)[31,32] or stroke frequency (6.0 cpd) for the text. The possibility that contrast adaptation was involved in myopia development led to the hypothesis that myopic children would show greater contrast adaptation than emmetropic children. Consistent with these expectations, both grating and reading tasks induced contrast adaptation in

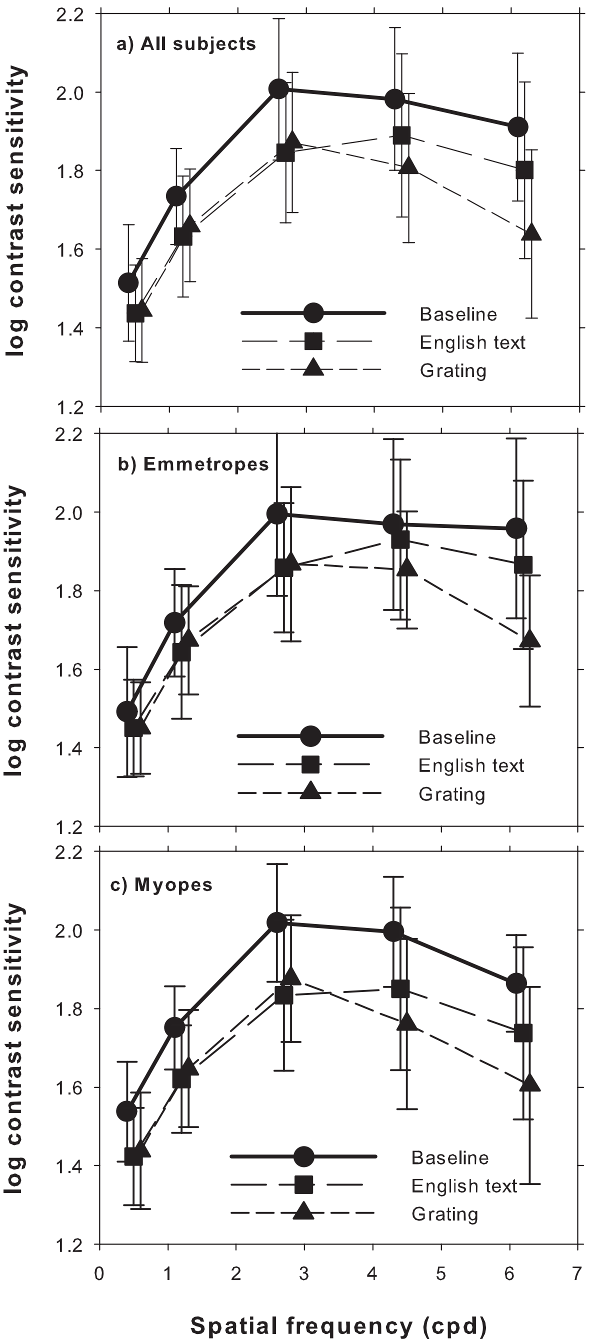

Figure 2. Mean ± SD log contrast sensitivities of (**a**) all participants, (**b**) emmetropic children, and (**c**) myopic children at baseline and during adaptation to English text and a horizontal sine-wave grating. To improve clarity, the plots are displaced horizontally slightly relative to each other.

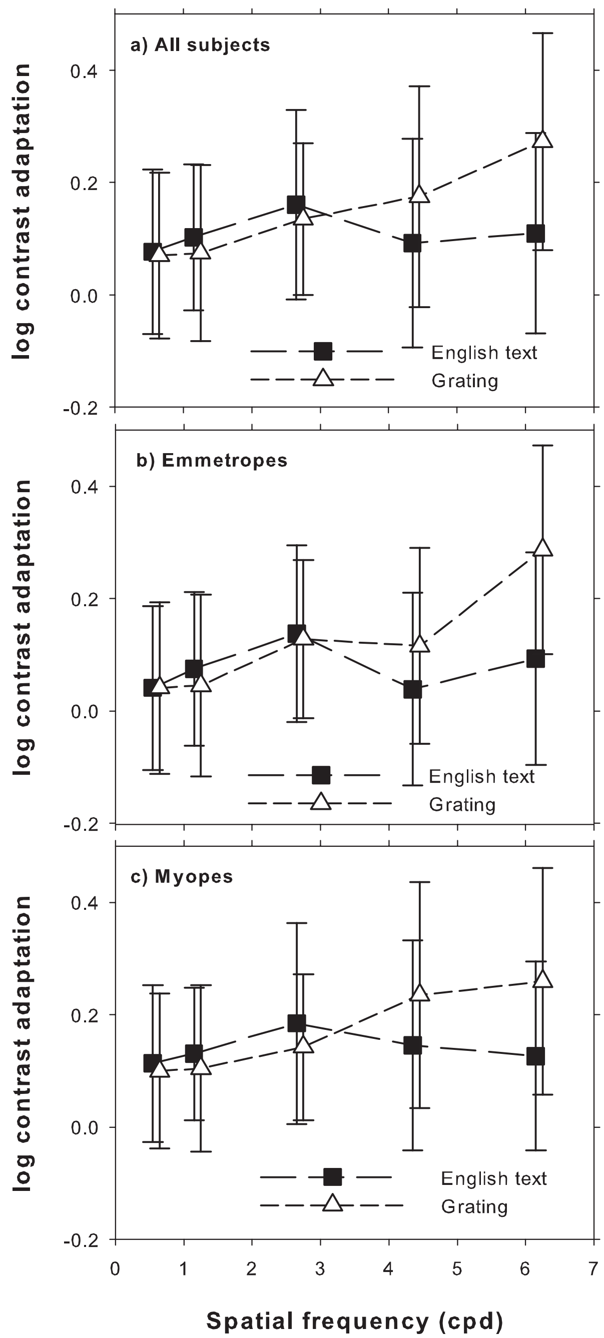

Figure 3. Mean ± SD log contrast adaptations of (**a**) all participants, (**b**) emmetropic children, and (**c**) myopic children to English text and a horizontal sine-wave grating. To improve clarity, the plots are displaced horizontally slightly relative to each other. Note that contrast adaptation was significant at most frequency/task combinations, adaptation was greater for gratings than for text, and myopes showed greater adaptation than emmetropes (mean, 0.05 log unit).

children, with myopes having significantly greater adaptation than emmetropes. Differences in the adaptation of emmetropic and myopic children were greatest at 4.4 cpd for both reading and for viewing the 6.2-cpd horizontal grating. The grating induced greater contrast adaptation than reading and, as expected, produced the greatest adaptation at this frequency (0.27 log unit). The text letters formed a broken uneven black row rather than the regular arrangement of the sine-wave grating and thus may have had less effective contrast at the row frequency; this could be the reason for the reduced adaptation to the text.

The contrast adaptation at 4.4 cpd induced by reading text was greater for the myopic children (0.145 log unit) than for the emmetropic children (0.039 log unit) by 0.106 log units (28%). Although this difference is small, it is substantially larger than the within-session variability of the measurement, which averaged 13%. We believe this difference in contrast adaptation is important; in animal models, minor changes in retinal image quality from translucent diffusers are more effective than opaque diffusers in producing high myopia.[15,33] The image degradation required to trigger deprivation myopia in monkeys is relatively low.[34] Smith and Hung[34] demonstrated that modest diffuser-induced reductions in object contrast ranging from 0.1 log unit at 0.125 cpd to 0.75 log units at 8 cpd for a 95% contrast target were sufficient to cause deprivation myopia in two out of three monkeys (approximately 4 D). Mon-Williams et al.[35] reported that a difference of contrast sensitivity of 0.1 log unit represents a real change in an individual's CSF since the CSF is normally stable. Therefore, although the contrast adaptation is small, it is likely to be sufficient to produce myopia. Also, the contrast adaptation and its potential myopigenic effect would likely increase with longer reading durations. However, further studies are needed to provide evidence for this.

Baseline Contrast Sensitivity

The children in our study had lower baseline contrast sensitivities, by 0.3 to 0.5 log units at 1 to 5 cpd, than previous studies.[36–39] One reason is that most of these studies measured contrast thresholds binocularly[37–39] instead of monocularly. Binocular viewing enhances contrast sensitivity.[40] The baseline contrast sensitivity was affected neither by the ethnic background of the children nor by the refractive error group. This is in agreement with previous studies indicating that myopia will not change contrast sensitivity if there is no retinal pathology.[41,42]

Spectacle Magnification

It might be considered that the emmetropes and myopes were presented with slightly different tasks because of the effects of spectacle magnification. However, this would not have been of significance. The small minification provided by spectacle lenses (8% for the maximum lens power –6 D at 15-mm pupil–lens back vertex distance) would be compensated by increases in axial length of myopes relative to those of emmetropes.

Generation of Defocus Signals

The decrease in firing of cortical neurons, which has been observed during contrast adaptation induced by gratings in animal studies,[43,44] may also occur during text-induced contrast adaptation. The neural response gain would decrease and may have a similar effect on neuronal activities as the degraded images caused by translucent diffusers, which are known to produce myopia in animal studies.[15,33] As a result, contrast adaptation could be perceived as a "defocus" signal from the retina and could potentially promote myopia development, with the greatest risk for myopia if contrast adaptation occurs at a young age when visual development is still very active. With children starting to read as young as 3 to 4 years of age, the neural plasticity that is present in this age group means that they are at increased risk for emmetropization disruption resulting from modification of visual inputs with prolonged near work. A possible mechanism could be that the decrease in retinal activity[45] during contrast adaptation results in altered release of neurotransmitters and neuromodulators, modifying scleral physiology and causing axial elongation.

Contrary to our findings, two previous studies[46,47] did not find contrast adaptation at spatial frequencies of 3 to 5 cpd. Ohlendorf and Schaeffel[46] measured contrast sensitivity in adults both before and after a period of myopic defocus (+4 D lens on the right eye for 10 minutes). They did not find a blur adaptation-induced change in contrast sensitivity for 3.2 cpd at 1-m viewing distance. The fact that their adapting stimuli were defocused images of low contrast (due to the +4 D defocus), whereas the adapting text and gratings used here were of high

Table 2. Contrast Adaptation during Reading Text and during Viewing a Horizontal Grating

	Adaptation Task									
	Reading English Text					Viewing 6.2 cpd High-Contrast Horizontal Grating				
Spatial Frequency	**0.5**	**1.2**	**2.7**	**4.4**	**6.2**	**0.5**	**1.2**	**2.7**	**4.4**	**6.2**
Mean contrast adaptation ±SD (log unit)										
All	0.077 ± 0.146	*0.102 ± 0.130	*0.161 ± 0.169	*0.092 ± 0.186	*0.110 ± 0.178	0.070 ± 0.147	0.075 ± 0.157	*0.135 ± 0.135	*0.175 ± 0.197	*0.273 ± 0.193
E	0.041 ± 0.146	0.075 ± 0.137	*0.138 ± 0.157	0.039 ± 0.170	0.093 ± 0.189	0.041 ± 0.153	0.045 ± 0.162	*0.128 ± 0.141	*0.115 ± 0.175	*0.287 ± 0.185
M	*0.113 ± 0.139	*0.130 ± 0.118	*0.184 ± 0.179	*0.145 ± 0.187	*0.126 ± 0.168	0.099 ± 0.138	0.104 ± 0.148	*0.142 ± 0.130	*0.235 ± 0.202	*0.259 ± 0.202
Mean adaptation difference (M–E)	0.072	0.055	0.046	0.106	0.033	0.058	0.059	0.014	0.120	−0.028

E, emmetropic children; M, myopic children.
* Contrast adaptation significance ($P < 0.05$).

contrast, could account for the differences in the findings. Related to the contrast of adapting stimuli, Georgeson reported that contrast adaptation occurs only when the test contrast is lower than the adapting contrast, and not when the test contrast is higher than the adapting contrast.[48] Similarly, in the study conducted by Rajeev and Metha,[47] the adapting stimuli were myopically defocused (+2 D for 30 minutes). Contrast sensitivity was measured when the defocus was first induced and at the end of the adapting period, at spatial frequencies of 0.5, 1, 2, 4, 8, and 12 cpd at 5 m. Rajeev and Metha measured contrast sensitivity in the presence of myopic defocus, whereas in our study, participants' contrast sensitivity was always tested with refractive errors corrected. Another possible reason for the differences between studies is that young adults were used in the previous two studies, whereas our study involved children.

One could argue that the contrast adaptation could be explained by accommodative inaccuracy as the child changed fixation between the adaptation and test stimuli, which were at different distances. The adapting task was at the closer distance (2.5 D), and the test stimuli at the further distance (1 D). If the participants stayed accommodated at near for a protracted time, this could produce myopic defocus on the contrast-sensitivity test pattern. However, the reported time required to change the accommodation response from 2.5 to 1 D is typically 0.25 to 0.30 seconds[49–51] and is similar for emmetropes and myopes[52–54]; thus this is unlikely to account for the observed findings. Moreover, the contrast-sensitivity test was performed at 1 m, a distance close to the tonic accommodation level and a distance considered to usually induce high focusing accuracy.[55] Although myopic children may have more near work–induced transient myopia (NITM) than emmetropic children after a period of near reading at 40 cm, the higher NITM is for viewing a distant target at 6 m and would not affect the contrast-sensitivity testing performed at 1 m. It is possible that myopes may have under-accommodated more for the near-adaptation task than emmetropes, as myopes have been reported to have greater lags of accommodation.[56–59] This might affect the clarity of the adaptation task and thus its spatial frequency distribution; in this situation, there would be a loss of the high spatial frequencies but the contrast sensitivity of the high spatial frequencies was not tested.

There are contradictory findings about the relative magnitudes of higher-order aberrations in emmetropic and myopic children.[60–62] On balance, these are unlikely to constitute factors contributing to contrast adaptation or development of myopia.

Real World Implication

The English text, in 12-point Times New Roman font, which we used as one of our adapting targets is commonly used in newspapers and books. Based on our findings, children should be encouraged to intermittently cease their reading activities to allow contrast-adaptation effects to dissipate. Brief interruptions to the reading task might be beneficial in limiting near work–induced progression of myopia, as has been proposed.[63] The intermittent breaks may involve outdoor activities, which have been shown to protect against myopia.[10] Outdoor activities may also expose the children to higher light intensity than that experienced when reading indoors; based on animal data, high light intensity may release myopia-suppressing factors.[64,65]

Limitations

One limitation of this study was that we were not able to determine what proportion of the emmetropic children would eventually develop myopia and whether the emmetropic children who went on to develop myopia were the ones who showed the greatest contrast adaptations. A longitudinal study would be required to determine this and also to shed light on whether the greater contrast adaptation in the myopic group is a cause or consequence of myopia development or progression.

Conclusions

Both grating and reading tasks induced contrast adaptation in children, with myopes having significantly greater adaptation than emmetropes. Differences in the adaptation of emmetropic and myopic children were greatest at 4.4 cpd for both reading and viewing horizontal gratings. Viewing a horizontal grating induced greater adaptation than that induced by reading text. Our findings imply that myopes are more susceptible to contrast adaptation. The effects of contrast adaptation may underlie the reported findings of prolonged near work being associated with myopia; however, our research does not show if this is consequential or causal.

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