1040-5488/10/8701-0004/0 VOL. 87, NO. 1, PP. 4–9
OPTOMETRY AND VISION SCIENCE

FEATURE ARTICLE ON LINE

Peripheral Defocus with Single-Vision Spectacle Lenses in Myopic Children

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ABSTRACT

Purpose. To determine the impact of wearing single-vision spectacle lenses (SVLs) on the refractive errors at the periphery of the retina in myopic eyes of Chinese children.

Methods. Twenty-eight children (8 to 15 years) were divided into two groups: one ($n = 17$) comprising children with low myopia (spherical equivalent between −0.75 D and −3.00 D inclusive) and the other ($n = 11$), with moderate myopia (spherical equivalent between −3.25 D and −6.00 D inclusive). Cycloplegic autorefraction from right eyes was measured at the fovea and at 20, 30, and 40° in the temporal and nasal visual fields. Measurements were taken on each subject both while uncorrected and while wearing SVLs.

Results. Hyperopic peripheral defocus was found with SVLs in both the low and moderate myopia groups. However, the increase in relative peripheral hyperopic defocus when wearing spectacle correction, when compared with the uncorrected state was statistically significant for the moderate myopia group only. In the moderate myopia group, relative peripheral hyperopic defocus when wearing spectacle correction was statistically significantly greater vs. the low myopia group at 40° in the nasal field and at both 30 and 40° in the temporal field ($p < 0.038$). An increase in astigmatism with correction was observed for J_{45} ($p < 0.05$) was also seen in eyes with moderate myopia, but this was limited to the nasal field.

Conclusions. Previous investigators have suggested that peripheral hyperopic defocus may play a role in the development and progression of myopia. We have shown that SVLs used to correct myopia can result in increased hyperopic defocus at the peripheral retina in the eyes of Chinese children. The magnitude of this increase tends to escalate with increasing refractive error and eccentricity, especially in cases with moderate levels of myopia.
(Optom Vis Sci 2010;87:4–9)

Key Words: myopia, peripheral defocus, single-vision spectacle lenses, children

The prevalence of myopia is higher in Asian populations in comparison with other populations[1–3]; in addition, its prevalence has been increasing over the past few decades.[4–7] Despite the intense efforts undertaken, the reasons for development and progression of myopia remain unknown.[5,8] To date, there has been no intervention found to be truly efficacious in preventing or retarding the progression of myopia.[2,9]

The idea that peripheral refractive error can alter on-axis refractive development in humans was first suggested in 1971.[10] Since then, several studies have suggested that peripheral defocus may play an important role both in myopia onset and myopia progression. Smith et al.[11] found that peripheral defocus can influence eye growth and refractive development in infant monkeys. Mutti et al.[12] suggested that relative (hyperopic) peripheral refractive error may be a risk factor for the onset and progression of myopia in children and that traditional spectacle lens designs do nothing to reduce or eliminate peripheral hyperopic defocus. Despite these and other studies[13–15] supporting the notion that peripheral refractive error plays an important role in the control of eye growth, to our knowledge, no study has reported the relationship between the wearing of single vision spectacle lenses (SVLs) for the correction of myopia and its impact on peripheral retinal defocus in children. This study aims to investigate the effects of SVLs on peripheral refractive error in a group of Chinese myopic children.

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METHODS

The study conformed to the tenets of the Declaration of Helsinki and was approved by the institutional ethics committee of

Zhongshan Ophthalmic Center. Informed consent was obtained from both children and parents after explanation and discussion of the nature of the study and the possible risks and benefits.

Twenty-eight children (8 to 15 years of age) of both genders (12 girls and 16 boys), and all Chinese ethnicity were enrolled from the outpatient department at the Zhongshan Ophthalmic Center. The inclusion criteria were OU having aspherical equivalent ametropia, as assessed by autorefraction, between −0.75 D and −6.00 D inclusive; astigmatism not more than −1.00 D; good visual acuity (best-corrected visual acuity better than 20/30); anisometropia <1.50 D, normal binocular function (no manifest strabismus or amblyopia), and no ocular pathology. Subjective refractive error was corrected with custom-made SVLs fitted with a vertex distance of 12 mm. Aspheric designs were excluded in this study, the base curves of lenses used in the study (front base curve) are shown in Table 1. OU were corrected to at least 6/6 Snellen visual acuity at 6 m and with a residual spherical equivalent no greater than ±0.25 D. Central (on-axis) spherical equivalent values were used to categorize the eyes into two groups: low myopia (−0.75 D to −3.00 D inclusive) and moderate myopia (−3.25 D to −6.00 D inclusive).

A Shin-Nippon (Grand Seiko) NVision–K5001 autorefractor (Shin Nippon, Tokyo, Japan) was used to measure central and peripheral refractive error. The instrument was modified to enable fixation points (red-light laser diodes) to be presented at different eccentricities, based on the optical center of the instrument.[16] Five measurements of refraction for the right eye at the corneal plane were taken at 0, 20, 30, and 40° in both the nasal (temporal retina) and temporal (nasal retina) visual fields at the corneal plane, with subjects fixating targets located at 3 m distance in both uncorrected and corrected conditions. For all measurements, subjects were asked to maintain straight-ahead fixation with OU and move their heads in the direction of the fixation target. During measurements, the instrument was aligned, such that the autorefractor's alignment reticle mark was centered on a clear image of the pupil. Care was taken to ensure that subjects used an appropriate degree of head turn when fixating peripheral targets, such that the spectacle plane remained at right angles to the visual axes. Measurements were conducted under ambient room lighting conditions between 150 and 160 lux.

To ensure both stabilized accommodation and adequate pupil size for central and peripheral autorefraction, an anticholinergic cycloplegic agent was used. One to 2 min after instillation of oxybuprocaine 0.4%, a single drop of tropicamide 1% was instilled in each eye. A second drop of tropicamide 1% was added after an additional 5 min. Refraction measurements commenced 20 min after instillation of the second tropicamide dose.

Data analysis was performed using SPSS 15.0 statistical software (Chicago, IL). Spherocylindrical refractive errors were converted into power vector form (M, J_{180}, and J_{45}) using the conventional formulas for astigmatic decomposition[17] before analysis. The relative peripheral refractive error (RPRE) was calculated to analyze the amount of change of the peripheral refractive power with respect to the foveal values. To analyze whether differences existed in the amount of peripheral refractive shift relative to the central refractive shift with SVLs between eyes with low and moderate myopia, the relative change of peripheral defocus (RCPD) was computed according to Eq. 1.

$$RCPD_i = (M_{ic} - M_{iu}) - (M_{0°c} - M_{0°u}) \quad (1)$$

Where, M is the mean spherical equivalent error measured at the eccentricity denoted by suffix i (where i represents −40, −30, −20, 20, 30, or 40°). Suffix 0° denotes measurement taken at the foveal/on-axis direction. Suffix c indicates corrected condition (with SVLs), and suffix u indicates uncorrected condition. The aforementioned variables were analyzed between conditions as a function of eccentricity for each refractive error group using a one-way analysis of variance with a level of significance set at $p < 0.05$.

TABLE 1.
Front base curve of both spherical and spherocylindrical lenses in diopters (D) used in this study

	n = 1.595	
	Lens power (D)	Base curve (D)
Spherical lenses	−1.00	+4.27
	−1.50	+4.27
	−2.00	+3.70
	−2.50	+3.98
	−3.00	+3.70
	−3.50	+3.13
	−4.00	+2.84
Spherocylindrical lenses		+3.41

RESULTS

The mean age of the 28 children who took part in this study was 12.5 ± 2.0 years (range 9 to 15 years). No differences in age existed between children with low myopia (12.7 ± 2.1 years) and children with moderate myopia (12.3 ± 2.0 years) ($p > 0.05$). The mean M ± SD was −2.30 ± 0.42 D (range −1.48 to −2.89 D) in the low myopia group and −4.27 ± 0.65 D (range −3.27 to −5.27 D) in the moderate myopia group. The overall results (M, J_{180}, J_{45}, and RPRE) from the low myopia and moderate myopia groups are summarized in Tables 2 and 3, respectively.

Spherical Equivalent (M)

Mean M from both low myopia and moderate myopia groups in the uncorrected and corrected states is shown in Fig. 1. In uncorrected low myopic eyes, myopic defocus was found at five of the six off-axis positions (T20, T30, T40, N20, and N30), whereas hyperopic defocus was found at N40 (0.44 ± 1.27 D). Similarly, in uncorrected moderate myopic eyes, myopic defocus was present at all off-axis positions. However, with spectacle correction, hyperopic defocus was found in all the six off-axis positions in both groups.

Relative Peripheral Refractive Error

The RPRE as a function of eccentricity and correction state in both low and moderate myopic eyes is shown in Fig. 2. In low myopic eyes with SVLs, relative hyperopic defocus increased

TABLE 2.
Results for mean M, J_{180}, and J_{45} and relative peripheral refractive error RPRE (mean ± standard deviation) for 17 low myopic eyes at seven different eccentricities

	Temporal field (nasal retina)			Central	Nasal field (temporal retina)		
	−40°	−30°	−20°	0°	20°	30°	40°
Uncorrected							
M	−0.57 ± 0.98	−1.30 ± 0.63	−1.94 ± 0.75	−2.30 ± 0.42	−2.06 ± 0.48	−0.98 ± 0.93	0.44 ± 1.27
J_{180}	−1.21 ± 0.35	−0.77 ± 0.20	−0.36 ± 0.37	0.10 ± 0.14	−0.45 ± 0.26	−0.93 ± 0.34	−1.35 ± 0.46
J_{45}	−0.08 ± 0.27	−0.09 ± 0.20	−0.02 ± 0.19	0.03 ± 0.12	0.12 ± 0.15	0.14 ± 0.22	0.16 ± 0.29
RPRE	1.73 ± 1.00	1.01 ± 0.66	0.36 ± 0.67	0.00 ± 0.00	0.24 ± 0.36	1.32 ± 0.75	2.75 ± 1.18
Corrected							
M	1.90 ± 0.93	1.02 ± 0.70	0.35 ± 0.65	−0.10 ± 0.13	0.13 ± 0.55	1.59 ± 0.86	3.12 ± 1.28
J_{180}	−1.12 ± 0.35	−0.74 ± 0.23	−0.46 ± 0.41	0.01 ± 0.09	−0.37 ± 0.20	−0.78 ± 0.34	−1.14 ± 0.56
J_{45}	−0.12 ± 0.37	−0.10 ± 0.23	−0.06 ± 0.16	0.02 ± 0.05	0.22 ± 0.15	0.27 ± 0.21	0.34 ± 0.32
RPRE	1.99 ± 0.96	1.11 ± 0.75	0.45 ± 0.69	0.00 ± 0.00	0.23 ± 0.50	1.68 ± 0.82	3.21 ± 1.26

TABLE 3.
Results for mean M, J_{180}, and J_{45} and relative peripheral refractive error RPRE (mean ± standard deviation) for 11 moderate myopic eyes at seven different eccentricities

	Temporal field (nasal retina)			Central	Nasal field (temporal retina)		
	−40°	−30°	−20°	0°	20°	30°	40°
Uncorrected							
M	−1.74 ± 1.14	−2.66 ± 1.40	−3.35 ± 1.36	−4.27 ± 0.65	−3.89 ± 1.07	−2.66 ± 1.10	−1.15 ± 1.15
J_{180}	−1.29 ± 0.32	−0.77 ± 0.19	−0.19 ± 0.34	0.13 ± 0.17	−0.39 ± 0.22	−0.87 ± 0.25	−1.47 ± 0.34
J_{45}	−0.28 ± 0.31	−0.26 ± 0.30	−0.10 ± 0.29	0.05 ± 0.08	0.26 ± 0.14	0.21 ± 0.18	0.24 ± 0.25
RPRE	2.53 ± 1.31	1.61 ± 1.47	0.92 ± 1.26	0.00 ± 0.00	0.38 ± 0.70	1.61 ± 0.84	3.12 ± 1.08
Corrected							
M	3.40 ± 1.39	2.14 ± 1.39	1.05 ± 1.17	−0.09 ± 0.13	0.56 ± 0.74	2.32 ± 1.06	4.29 ± 1.46
J_{180}	−1.16 ± 0.30	−0.77 ± 0.17	−0.60 ± 0.23	−0.04 ± 0.14	−0.39 ± 0.27	−0.70 ± 0.27	−1.00 ± 0.54
J_{45}	−0.53 ± 0.54	−0.34 ± 0.33	−0.04 ± 0.23	0.04 ± 0.07	0.40 ± 0.18	0.55 ± 0.29	0.82 ± 0.33
RPRE	3.49 ± 1.40	2.23 ± 1.41	1.14 ± 1.17	0.00 ± 0.00	0.65 ± 0.70	2.41 ± 1.00	4.39 ± 1.42

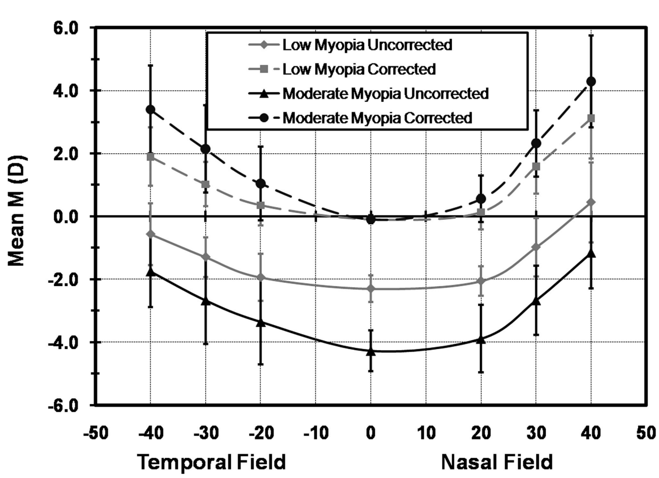

FIGURE 1.

Spherical equivalent (M) in diopters along the horizontal field in uncorrected and corrected eyes with low myopia and moderate myopia. Error bars indicate 1 ± standard deviation.

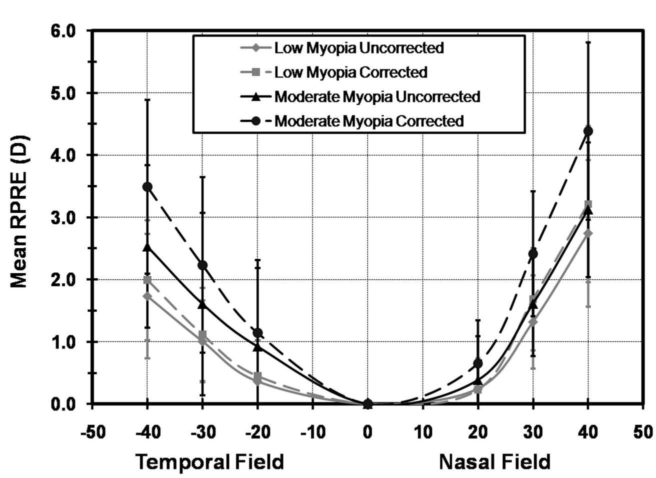

FIGURE 2.

Relative peripheral refractive error (RPRE) along the horizontal field in uncorrected and corrected eyes with low myopia and moderate myopia. Error bars indicate 1 ± standard deviation.

slightly with eccentricity, but it was not statistically significant ($p > 0.05$). On the other hand, in moderate myopic eyes with SVLs, the relative hyperopic defocus also increased with eccentricity and was statistically significant at 40° ($p = 0.03$) on the nasal field only. Although the mean RPRE values in the uncorrected state were not different ($p > 0.05$) between both refractive groups, in the corrected state, moderate myopic eyes had significantly more relative hyperopic defocus at T40° ($p = 0.007$), T30° ($p = 0.03$), and N40° ($p = 0.038$) than low myopic eyes.

Relative Change of Peripheral Defocus

In respect of the RCPD, in all six off-axis positions, there was a significant difference between low and moderate myopic eyes ($p < 0.05$, all positions) (Fig. 3). The relative change in low myopic eyes was less than that in moderate myopic eyes, with moderately myopic eyes exhibiting more hyperopic defocus.

Astigmatism (J_{180} and J_{45})

The mean results of J_{180} and J_{45}, from both low myopia and moderate myopia groups in the uncorrected and corrected states are shown in Figs. 4 and 5, respectively. The mean levels of J_{180} (on and off-axis) were similar between low and moderate myopic eyes in both uncorrected and corrected conditions ($p > 0.05$). There was an effect on astigmatism with correction in both myopic groups. On-axis, there was a reduction in the mean values of central J_{180} ($p < 0.05$) with correction in both low and moderate myopic eyes. Off-axis, J_{180} (absolute) values increased at 20° temporal field with correction only in moderate myopic eyes by 0.41 D ($p < 0.05$), and they tend to decrease with correction in both low and moderate myopic eyes for most eccentricities but did not significantly decrease with correction in both low and moderate myopic eyes at the other eccentricities ($p > 0.05$). In contrast to on-axis values, off-axis J_{180} values did not decrease significantly with correction as a function of eccentricity in either group ($p > 0.05$).

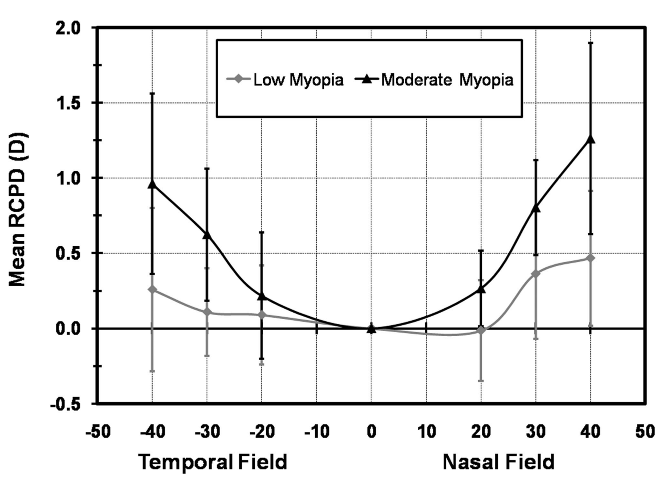

FIGURE 3.
Relative change of peripheral defocus (RCPD) along the horizontal field for eyes with low myopia and moderate myopia. Error bars indicate 1 ± standard deviation.

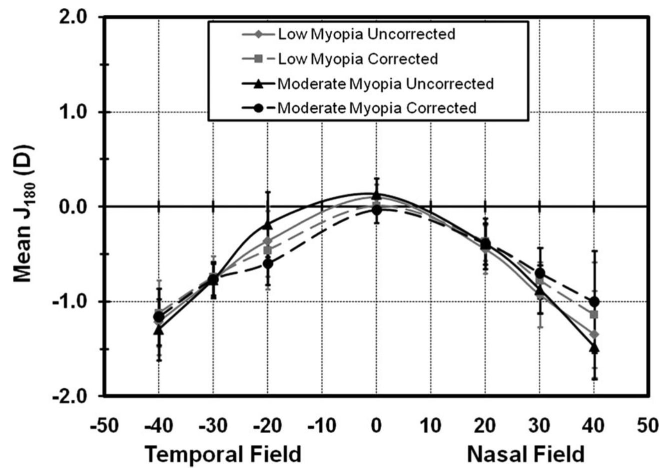

FIGURE 4.
Vertical/horizontal astigmatism (J_{180}) in diopters along the horizontal field in uncorrected and corrected eyes with low myopia and moderate myopia. Error bars indicate 1 ± standard deviation.

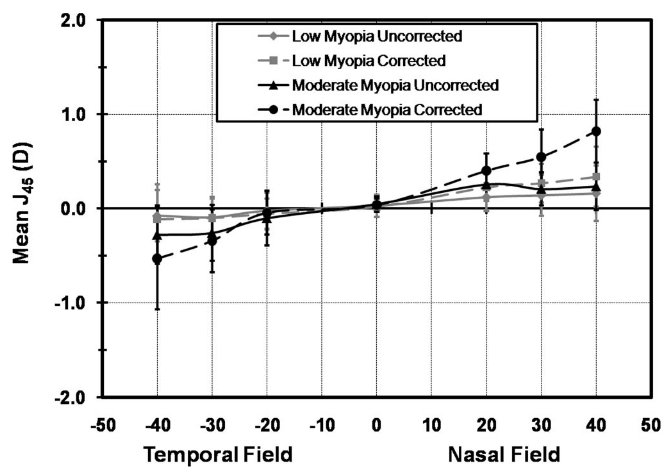

FIGURE 5.
Oblique astigmatism (J_{45}) in diopters along the horizontal field in uncorrected and corrected eyes with low myopia and moderate myopia. Error bars indicate 1 ± standard deviation.

When spectacles were worn, J_{45} values in the periphery were significantly higher in moderate myopic eyes when corrected than low myopic eyes in the temporal field at 30° ($p = 0.04$) and at 40° ($p = 0.05$) and also in the nasal field at 20° ($p = 0.02$), 30° ($p = 0.01$), and at 40° ($p = 0.001$). In addition, the levels (absolute and relative to on-axis values) of J_{45} increased with eccentricity in the nasal field (20, 30, and 40°) in moderate myopic eyes ($p < 0.05$) only.

DISCUSSION

Our results are in agreement with previously published reports that demonstrate relative hyperopia in the horizontal retinal periphery of uncorrected myopic eyes.[13,18–21] However, the relative hyperopia observed in our study population was higher than that reported from a group of (mostly white) myopic children (+0.80 ± 1.29 D, 30° nasal field) with a similar age range (6 to 14 years) and myopic refractive error (−2.84 ± 2.09 D).[21] It is well known that the prevalence of myopia in children is higher in Chinese population[22] in comparison with a white population,[23] and the annualized progression of myopia is also greater in the Chinese population.[24] Thus, the increased relative peripheral hyperopia observed in our population may provide some evidence of ethnic differences in eye shape or distortion in myopic Chinese children and consequently provide us with an alternate explanation for the differences seen in progression of myopia in children from different ethnicity.

It has been hypothesized that peripheral hyperopia provides a stimulus for axial elongation and progression of myopia as measured at the fovea.[25] Also, studies in infant monkeys showed that from deprivation in the retinal periphery despite clear images at the fovea can produce axial myopia at the fovea.[11] Our data show that when uncorrected, the myopic eye experiences absolute myopic defocus along the horizontal visual field. However, when corrected with SVLs, the myopic eye experiences absolute hyperopic defocus at the periphery, which may be associated with the progression of myopia. More importantly, when the magnitude of hyperopic defocus was compared between corrected vs. uncorrected states, it was seen the correcting SVLs increased the amount of hyperopic defocus in eyes with moderate myopia. Calver et al.[26] using trial lenses to correct adults with low myopia did not find differences in peripheral mean spherical equivalent error between corrected and uncorrected state of myopia. Although our results concur with Calver et al. for the low myopic group, we found a significant increase in hyperopic defocus with SVLs for the moderately myopic group. This increase was present at all the peripheral angles that were assessed and was as expected due to higher powered negative lenses being prescribed for moderate myopic eyes. Given these results, the question then asked is to whether correction with SVLs is likely to accelerate myopia progression. Smith et al.[11] suggested that prescribing lenses that impose hyperopic defocus in the periphery could effectively promote axial elongation and suggested it may be possible to slow the progression of myopia in children by prescribing lenses that correct central refractive errors and at the same time increase the curvature of field of the image plane, thus either correcting for any peripheral hyperopia or actually imposing myopic defocus in the periphery. Because of the cross-sectional nature and the methodology adopted in this study, we are unable to draw any inferences on the effect of hyperopic defocus with SVLs on progression of myopia. Studies considering the peripheral refractive error state of stable myopic eyes vs. progressive myopic eyes with SVLs or a longitudinal study monitoring the progression of myopia with or without interventions will shed more light on this issue. However, despite the lack of the evidence for efficacy in terms of control of progression of myopia, it could be argued that a correcting lens that reduces or eliminates hyperopic defocus may have inherent advantages over the present form of spectacles in optimizing aspects of peripheral visual performance such as detection acuity. Wang et al.[27] demonstrated that grating detection acuity depends strongly on optical blur in the periphery, and Whatham et al.[28] demonstrated that contrast sensitivity at peripheral retinal locations improved with correction of peripheral refractive errors.

In agreement with previous data, asymmetry was observed in the peripheral refraction with the temporal retina being more hyperopic in comparison with nasal retina.[29] Also, astigmatism increased with an increase in eccentricity in the uncorrected myopic eyes.[19] These findings have been suggested to be the result of the combined effects of the cornea, crystalline lens, and retina.[30] Correction with SVLs had a small impact on the magnitude of J_{180} in both the low and moderate myopic eyes; however, J_{45} increased with eccentricity, especially in moderate myopic eyes. One possible explanation for this increase is the pantoscopic tilt induced by spectacle lenses.[31] We rule out misalignment of the spectacle lenses as a possible explanation for this increase as the methodology adopted in the study involved the use of appropriate head turn to ensure that the spectacle plane was always at right angles to the visual axis. Furthermore, for the farthest peripheral angle measured in the study, i.e., 40° the rays passed approximately 15 to 20 mm from the lens center and therefore was not subject to increased astigmatism and other aberrations.

In conclusion, our results provide evidence that correction of SVLs induced absolute hyperopic defocus on the retinal periphery of low and moderate myopic eyes. Although the effect of this induced hyperopia on the progression of myopia at the fovea remains to be assessed, it is reasonable to suppose that improving on the designs of the existing optical interventions may confer additional benefits.

ACKNOWLEDGMENTS

We thank Mr. Les Donovan for his help with the preparation of this article.

The authors proprietary interests in any of the products or devices are mentioned in the article.

Received March 24, 2009; accepted August 12, 2009.

REFERENCES

1. He M, Zeng J, Liu Y, Xu J, Pokharel GP, Ellwein LB. Refractive error and visual impairment in urban children in southern China. Invest Ophthalmol Vis Sci 2004;45:793–9.
2. Saw SM, Katz J, Schein OD, Chew SJ, Chan TK. Epidemiology of myopia. Epidemiol Rev 1996;18:175–87.
3. Sperduto RD, Seigel D, Roberts J, Rowland M. Prevalence of myopia in the United States. Arch Ophthalmol 1983;101:405–7.
4. Sveinsson K. The refraction of Icelanders. Acta Ophthalmol (Copenh) 1982;60:779–87.
5. Villarreal MG, Ohlsson J, Abrahamsson M, Sjostrom A, Sjostrand J. Myopisation: the refractive tendency in teenagers. Prevalence of myopia among young teenagers in Sweden. Acta Ophthalmol Scand 2000;78:177–81.
6. Lin LL, Shih YF, Tsai CB, Chen CJ, Lee LA, Hung PT, Hou PK. Epidemiologic study of ocular refraction among schoolchildren in Taiwan in 1995. Optom Vis Sci 1999;76:275–81.
7. Hosaka A. The growth of the eye and its components. Japanese studies. Acta Ophthalmol Suppl 1988;185:65–8.
8. Lee KE, Klein BE, Klein R, Wong TY. Changes in refraction over 10 years in an adult population: the Beaver Dam Eye study. Invest Ophthalmol Vis Sci 2002;43:2566–71.
9. Saw SM, Shih-Yen EC, Koh A, Tan D. Interventions to retard myopia progression in children: an evidence-based update. Ophthalmology 2002;109:415–21.
10. Hoogerheide J, Rempt F, Hoogenboom WP. Acquired myopia in young pilots. Ophthalmologica 1971;163:209–15.
11. Smith EL III, Kee CS, Ramamirtham R, Qiao-Grider Y, Hung LF. Peripheral vision can influence eye growth and refractive development in infant monkeys. Invest Ophthalmol Vis Sci 2005;46:3965–72.

12. Mutti DO, Hayes JR, Mitchell GL, Jones LA, Moeschberger ML, Cotter SA, Kleinstein RN, Manny RE, Twelker JD, Zadnik K. Refractive error, axial length, and relative peripheral refractive error before and after the onset of myopia. Invest Ophthalmol Vis Sci 2007;48:2510–9.
13. Schmid GF. Variability of retinal steepness at the posterior pole in children 7–15 years of age. Curr Eye Res 2003;27:61–8.
14. Seidemann A, Schaeffel F, Guirao A, Lopez-Gil N, Artal P. Peripheral refractive errors in myopic, emmetropic, and hyperopic young subjects. J Opt Soc Am (A) 2002;19:2363–73.
15. Stone RA, Flitcroft DI. Ocular shape and myopia. Ann Acad Med Singapore 2004;33:7–15.
16. Whatham A, Zimmermann F, Martinez A, Delgado S, de la Jara PL, Sankaridurg P, Ho A. Influence of accommodation on off-axis refractive errors in myopic eyes. J Vis 2009;9:1–13. Available at: http://www.journalofvision.org/9/3/14/. Accessed September 1, 2009.
17. Thibos LN, Wheeler W, Horner D. Power vectors: an application of Fourier analysis to the description and statistical analysis of refractive error. Optom Vis Sci 1997;74:367–75.
18. Atchison DA, Pritchard N, Schmid KL, Scott DH, Jones CE, Pope JM. Shape of the retinal surface in emmetropia and myopia. Invest Ophthalmol Vis Sci 2005;46:2698–707.
19. Millodot M. Effect of ametropia on peripheral refraction. Am J Optom Physiol Opt 1981;58:691–5.
20. Rempt F, Hoogerheide J, Hoogenboom WP. Peripheral retinoscopy and the skiagram. Ophthalmologica 1971;162:1–10.
21. Mutti DO, Sholtz RI, Friedman NE, Zadnik K. Peripheral refraction and ocular shape in children. Invest Ophthalmol Vis Sci 2000;41:1022–30.
22. Lam CS, Edwards M, Millodot M, Goh WS. A 2-year longitudinal study of myopia progression and optical component changes among Hong Kong schoolchildren. Optom Vis Sci 1999;76:370–80.
23. Kleinstein RN, Jones LA, Hullett S, Kwon S, Lee RJ, Friedman NE, Manny RE, Mutti DO, Yu JA, Zadnik K. Refractive error and ethnicity in children. Arch Ophthalmol 2003;121:1141–7.
24. Grosvenor T, Goss DA. Clinical Management of Myopia. Boston: Butterworth-Heinemann; 1999.
25. Wallman J, Winawer J. Homeostasis of eye growth and the question of myopia. Neuron 2004;43:447–68.
26. Calver R, Radhakrishnan H, Osuobeni E, O'Leary D. Peripheral refraction for distance and near vision in emmetropes and myopes. Ophthal Physiol Opt 2007;27:584–93.
27. Wang YZ, Thibos LN, Bradley A. Effects of refractive error on detection acuity and resolution acuity in peripheral vision. Invest Ophthalmol Vis Sci 1997;38:2134–43.
28. Whatham A, Ho A, Sankaridurg P, Conrad F, Falk D, Lazon de la Jara P, Holden B. Contrast sensitivity at peripheral retinal locations of emmetropic and myopic eyes is equivalently affected by imposed defocus. In: McBrien NA, Morgan IG, eds. Myopia: Proceedings of the 12th International Myopia Conference; Cairns, Australia, July 8–12, 2008. Optom Vis Sci 2008;86:E67–73.
29. Logan NS, Gilmartin B, Wildsoet CF, Dunne MC. Posterior retinal contour in adult human anisomyopia. Invest Ophthalmol Vis Sci 2004;45:2152–62.
30. Atchison DA, Pritchard N, Schmid KL. Peripheral refraction along the horizontal and vertical visual fields in myopia. Vision Res 2006;46:1450–8.
31. Bakaraju RC, Ehrmann K, Ho A, Papas EB. Pantoscopic tilt in spectacle-corrected myopia and its effect on peripheral refraction. Ophthalmic Physiol Opt 2008;28:538–49.

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