CLINICAL AND EXPERIMENTAL
OPTOMETRY

RESEARCH

Contrast sensitivity of amblyopic eyes in children with myopic anisometropia

Clin Exp Optom 2019; 102: 57–62 DOI:10.1111/cxo.12817

Yi Pang OD PhD
Megan Allen OD
Joshua Robinson OD
Kelly A Frantz OD
Illinois College of Optometry, Chicago, Illinois, USA
E-mail: ypang@ico.edu

Submitted: 23 March 2018
Revised: 15 June 2018
Accepted for publication: 27 June 2018

Background: Contrast sensitivity function (CSF) in amblyopes has been studied extensively, with few studies on amblyopia associated with myopic anisometropia. The purpose of this study was to investigate CSF of amblyopic eyes in children with myopic anisometropia compared to fellow eyes of the amblyopic children, as well as to control subjects with high myopia but no amblyopia.

Methods: Twenty amblyopic children with myopic anisometropia (range of visual acuity in the amblyopic eye: 6/10 to 6/100) and 16 control subjects with high myopia (< −6.00 D) but no amblyopia were recruited. CSF with linear sine-wave gratings was assessed at 1.5, 3, 6, 12 and 18 cycles per degree (cpd) in the amblyopic, fellow and control myopic eyes. Multivariate analysis of variance was used to compare logCS of the amblyopic, fellow and control myopic eyes after adjusting for age and race.

Results: The average degree of myopia in the amblyopic eyes was −10.46 D (range: −5.00 to −18.25 D). The average degree of myopia in the right eyes of control subjects was −8.61 D (range: −6.25 to −13 D). A statistically significant difference was found in logCS among the three groups of eyes at all frequencies ($p < 0.001$) except at 1.5 cpd. CSF of amblyopic eyes was statistically significantly lower than that of control myopic eyes at 3, 6, 12 and 18 cpd but not at 1.5 cpd. No significant difference in logCS was found between control myopic and fellow eyes. The co-variates (age and race) were not significantly related to the logCS ($p > 0.05$). Reduced CSF of the amblyopic eyes at the middle frequencies was associated with the degree of anisometropia.

Conclusion: CSF at the middle and higher frequencies was reduced in the amblyopic eyes associated with myopic anisometropia compared to the fellow eyes of the same amblyopic children as well as to eyes of control subjects with high myopia but no amblyopia.

Key words: amblyopia, anisometropia, children, contrast sensitivity, myopia

Amblyopia is defined as a unilateral or bilateral decrease of visual acuity (VA) caused by pattern vision deprivation or abnormal binocular interaction, including anisometropia and strabismus, not due to pathology in the eye or visual pathway.[1] It is the most common reason for monocular visual impairment in children and young- and middle-aged adults.[2,3]

VA is the key factor for diagnosing amblyopia and measuring amblyopia treatment outcomes.[4–7] However, VA only represents one aspect of visual function, the smallest high contrast stimulus that can be detected.[8] The majority of objects viewed in daily life have lower contrast than those used for VA testing. The contrast sensitivity function (CSF) is determined by measuring contrast thresholds as a function of object size (spatial frequency).[9] CSF testing allows evaluation of visual performance in the low and middle spatial frequency ranges in addition to high frequency.[10] Numerous ocular diseases and abnormalities affect CSF more than VA.[11,12] Therefore, eye-care practitioners may misdiagnose and/or improperly treat patients if CSF is not measured.

CSF is often reduced in both anisometropic and strabismic types of amblyopia.[13–16] Previous studies of CSF in anisometropic amblyopia focused purely on hyperopic anisometropia or included only one or two cases of myopic anisometropia in their analyses.[13,16,17] Bradley and Freeman[16] were the only ones to report on CSF in the myopic anisometropia condition. They found amblyopic eyes associated with myopic anisometropia had reduced CSF at the middle and higher frequencies compared to the fellow eyes. However, only two amblyopic subjects with myopic anisometropia were included in their study.[16] In addition, they did not include control subjects with high myopia in their study. Thus, their findings in myopic anisometropia could be due to myopia, amblyopia, or both conditions.

Amblyopia due to myopic anisometropia is relatively rare in the general population; therefore, it is rarely reported. However, such patients are seen regularly in eye-care clinics. The authors have previously reported on amblyopia treatment outcomes and macular anomalies in myopic anisometropic amblyopia.[18–20] The purpose of this study was to evaluate CSF of amblyopic eyes with myopic anisometropia compared to the fellow eyes of the same amblyopic subjects

as well as to eyes of control subjects with high myopia but no amblyopia. In addition, the association between the CSF and degree of anisometropia was investigated.

Methods

Study population and data collection

Both the study protocol and informed consent forms were approved by the Institutional Review Board of the Illinois College of Optometry. In accordance with the guidelines of the Declaration of Helsinki, written informed consent was obtained from the parent or legal guardian of each child and from subjects who were at least 18 years old.

Twenty subjects diagnosed with myopic anisometropic amblyopia – seen at the Illinois Eye Institute, an urban ambulatory eye clinic – were enrolled into the study. Sixteen control subjects with bilateral high myopia magnitude matching that of our amblyopic subjects, but without amblyopia, were enrolled from the Illinois Eye Institute and Illinois College of Optometry students/employees. Eligibility criteria are listed in Table 1. Other than refractive error and amblyopia, the subjects had no concurrent ocular disease.

All subjects underwent a comprehensive eye examination including monocular distance VA, cover test at distance and near, stereoacuity with both the Randot Preschool Stereoacuity Test (Stereo Optical, http://www.stereooptical.com) and Stereo Fly, visuoscopy, manifest refraction, cycloplegic retinoscopy (for subjects < 18 years old), and dilated fundus examination with indirect ophthalmoscopy. Monocular distance VA was tested at three metres using a computer-based electronic VA tester[21,22] which is commonly used in amblyopia studies.[23,24] Single character optotypes with surrounding bars were used according to the Amblyopia Treatment Study VA protocol.[25] Cycloplegia was induced in subjects younger than 18 years old with one drop each of one per cent cyclopentolate, one per cent tropicamide and 2.5 per cent phenylephrine.

Attempts were made to match age, race and myopia magnitude between control and amblyopic subjects. However, in a previous study by the authors,[18] it was not possible to enrol age-matched control subjects who had bilateral equal, high myopia and were non-amblyopic (VA of $6/6^{+2}$ or better) with myopia of a magnitude that matched the amblyopic subjects. In addition, previous studies by the authors showed that myopic anisometropic amblyopia occurred much more commonly in African-American subjects than in other races.[18–20] However, bilateral high myopia with normal vision was not common in an African-American population based on clinical experience and the patient chart review process. Thus, it was not possible to match race between control and amblyopic subjects.

Criteria for amblyopic subjects
Age: 7 to < 18 years
Best-corrected visual acuity (VA) in the amblyopic eye 6/10 to 6/120 inclusive
Best-corrected VA in the sound eye 6/10 or better
Myopic anisometropia more than 3.00 D
Interocular acuity difference > 2 logMAR lines
Amblyopia associated with myopic anisometropia
No amblyopia treatment in the past one month
No ocular pathology causing reduced visual acuity
No prior ocular surgery
Criteria for control subjects (bilateral high myopia without amblyopia)
Age: 7 to < 30 years
Best-corrected VA 6/8 or better right eye and left eye
High myopia (< −6.00 D) in both eyes
No anisometropia more than 1.00 D
No ocular pathology causing reduced visual acuity
No prior ocular surgery

Table 1. Eligibility and exclusion criteria

Myopia was fully corrected. For amblyopic subjects with hyperopia in their fellow eye, hyperopic correction was reduced by no more than 1.50 D from the cycloplegic refraction. Only one of the 20 amblyopic subjects had a cycloplegic refraction > +1.00 D in the fellow eye (Table 3); thus, the residual anisometropia caused by undercorrected hyperopia was minimal, especially considering that contrast sensitivity was tested under non-cycloplegic condition.

Subjects wore their refractive correction for at least two weeks before the CSF measurement. Linear sine-wave grating test (M&S Technologies, http://www.mstech-eyes.com/) was used to evaluate each eye. CSF was assessed using a four-alternative forced-choice (4AFC: vertical, tilted clockwise, horizontal, or tilted counter-clockwise) procedure, paired with a staircase method of limits. Subjects were required to correctly identify the grating orientation by holding up a pen and matching the orientation of the pen to the orientation of the grating. Five spatial frequencies were tested: 1.5, 3, 6, 12 and 18 cycles per degree (cpd). The lowest and highest luminance values of the screen were 0.1 cd/m^2 (surrounding the stimulus) and 85 cd/m^2 with the mean luminance of 42.5 cd/m^2. The monitor had a pixel resolution of 1,280 × 1,024. The field size was 3.88 degrees and contrast resolution was 24 bits. Contrast linearity was gamma corrected. The target was on for five seconds and off for five seconds to control the effect of after-image on the following test target.

A demonstration was shown to each subject displaying a target of 6 cpd at 50, 25, 12.5 and six per cent contrast. After the subjects were familiar with the test procedure, the test began at 25 per cent contrast. Threshold was determined after three reversals. Step size was initially 0.3 log units and then changed to 0.2 log units after the first incorrect response. The test went up 0.2 log units and reduced in 0.2 log unit steps until the next incorrect answer. Finally, the test moved up 0.1 log unit and reduced contrast until the final incorrect answer. The best (lowest) two contrast levels were averaged for the final result. The luminance of the test room was controlled at a level of 0.70 cd/m^2.

Data analysis

To analyse refractive error, spherical equivalent was used, which is the spherical power plus half of the minus cylinder power from the cycloplegic refraction. VA was converted to log of the minimum angle of resolution (logMAR) for analysis. Threshold values for each CSF measure were transformed to log values (logCS) for data analysis. Only the data from the right eyes of control subjects were used for analysis.

Multivariate analysis of variance (MANOVA) was used to compare logCS of the amblyopic, fellow, and control myopic eyes after adjusting for age and race. The Kolmogorov–Smirnov test was used to check the normality of distributions for spherical equivalent and logCS at 1.5, 3, 6, 12 and 18 cpd in amblyopic, fellow and control

Characteristic	Amblyopic subjects (n = 20)	Controls (n = 16)
Gender		
Female	11	10
Male	9	6
Race		
Black	16	1
Caucasian	0	7
Asian	2	8
Hispanic	2	0
Age (years)		
Mean	11.1	24.2
SD	3.2	2.5

Table 2. Characteristics of amblyopic subjects (n = 20) and control myopic subjects (n = 16)

myopic eyes. All parameters were normally distributed. The interocular difference (IOD) between amblyopic and fellow eyes in spherical equivalent and logCS were also normally distributed.

To test whether IOD of logCS was associated with degree of anisometropia in the amblyopic subjects, partial correlation was performed while controlling for the age of the subject. All data were analysed using Statistical Package for Social Sciences (IBM SPSS version 21.0; IBM, Armonk, New York, USA). A p-value of < 0.05 was considered statistically significant.

Results

General characteristics of control and amblyopic subjects are listed in Table 2. VA of the amblyopic eyes ranged from 6/10 to 6/100. The average degree of myopia in the amblyopic eyes was −10.46 D (range: −5.00 to −18.25 D). The average degree of myopia in the right eyes of control subjects was −8.61 D (range: −6.25 to −13 D). Spherical equivalent in the amblyopic eyes had no statistically significant difference compared to that in the control eyes ($p > 0.05$). Table 3 shows the clinical profiles of the subjects with myopic anisometropic amblyopia.

Table 4 lists the means of logCS in amblyopic, fellow and control myopic eyes. The CSF reduction of the amblyopic eyes at 1.5, 3, 6, 12 and 18 cpd was 28.9, 31.3, 44.0, 65.1 and 57.5 per cent, respectively compared to the control myopic eyes. Using Pillai's trace, a significant difference in CSF at 1.5, 3, 6, 12 and 18 cpd was found among amblyopia, fellow and control eyes ($V = 0.74$, $F_{(10,\ 265)} = 5.69$, $p < 0.001$). Race ($p = 0.83$) and age ($p = 0.71$) had no significant effect on CSF. Separate univariate ANOVAs on the CSF at each frequency revealed that amblyopia had significant effects on all CSF frequencies (all p-values < 0.001) except at 1.5 cpd ($p = 0.11$). Post hoc analysis (one-way MANOVA with Bonferroni correction) identified statistically significant differences between amblyopic and control myopic eyes as well as between amblyopic and fellow eyes at 3, 6, 12 and 18 cpd but not at 1.5 cpd. No significant difference in logCS was found between control myopic and fellow eyes.

In an additional analysis, data from the five amblyopic subjects who had myopia < -13.00 D were removed so refractive error in the remaining amblyopic eyes (n = 15) was matched with control myopic eyes (n = 16). LogCS was compared among amblyopic eyes, fellow eyes and control myopic eyes using the same MANOVA

Patient	Age (years)	Stereopsis		Amblyopic eye				Fellow eye			
		Fly	Preschool	logMAR VA	Sphere (D)	Cylinder (D)	Axis	logMAR VA	Sphere (D)	Cylinder (D)	Axis
1	9.1	(−)	Nil	0.90	−13.00	Sphere		0.00	PL		
2	7.5	(+)	Nil	0.70	−7.75	−2.25	180	0.00	PL	−0.75	180
3	9.5	(+)	Nil	1.10	−13.00	Sphere		0.20	−1.50	Sphere	
4	7.8	(−)	Nil	0.90	−14.50	−2.25	135	0.20	−1.50	−2.50	30
5	9.4	(+)	60″	0.20	−5.00	−3.00	180	0.00	−0.50	−1.50	180
6†	15.7	(−)	Nil	0.60	−12.50	−2.50	160	0.20	−5.50	−3.00	180
7	16.7	(+)	Nil	0.80	−6.00	−1.00	20	0.00	−1.50	−0.50	170
8	15.7	(−)	Nil	1.20	−17.75	−1.00	15	0.10	−1.75	−1.50	180
9†	12.8	(−)	Nil	1.00	−12.00	−2.75	180	0.00	+0.50	−0.75	180
10	7.7	(+)	100″	0.20	−5.00	−2.25	180	0.00	+1.25	−2.50	180
11	8.0	(+)	200″	0.30	−8.50	Sphere		0.00	+0.50	Sphere	
12	9.0	(−)	Nil	0.90	−8.25	−0.50	150	0.00	−1.50	Sphere	
13	10.8	(+)	Nil	0.60	−5.50	−1.50	180	0.10	+0.50	−1.00	15
14	15.7	(+)	800″	0.40	−10.75	−1.50	60	0.20	−4.75	−0.75	180
15	10.7	(+)	Nil	1.00	−11.00	Sphere		0.10	+0.25	−0.25	180
16	8.2	(+)	100″	0.40	−8.00	−2.50	170	0.10	−0.75	−2.25	180
17	11.7	(+)	Nil	0.70	−15.00	−1.50	10	0.00	−3.00	Sphere	
18	16.2	(−)	Nil	1.20	−13.00	Sphere		0.00	+0.50	Sphere	
19	9.5	(+)	800″	0.50	−4.50	−1.00	60	−0.10	+0.50	−0.50	180
20	10.4	(+)	Nil	0.50	−6.50	−2.50	180	0.00	+1.00	Sphere	

VA: visual acuity.
†Indicates subjects with combined mechanism amblyopia (both myopic anisometropic and strabismic amblyopia).

Table 3. Clinical profiles of subjects with myopic anisometropic amblyopia

Contrast sensitivity frequency	Amblyopic eyes Mean (95% CI)	Fellow eyes Mean (95% CI)	Control eyes Mean (95% CI)	F (2,53) value	p-value
1.5 cpd	1.09 (0.82–1.37)	1.44 (1.17–1.72)	1.54 (1.42–1.66)	2.35	p = 0.11
3 cpd	1.27 (1.01–1.53)	1.91 (1.76–2.05)	1.85 (1.72–1.97)	12.33	p < 0.0001*
6 cpd	0.99 (0.76–1.22)	1.91 (1.76–2.06)	1.77 (1.58–1.97)	25.89	p < 0.0001†
12 cpd	0.51 (0.34–0.69)	1.36 (1.12–1.59)	1.47 (1.33–1.62)	27.01	p < 0.0001‡
18 cpd	0.47 (0.28–0.66)	0.93 (0.68–1.18)	1.10 (0.95–1.25)	8.35	p < 0.001§

CI: confidence interval, cpd: cycles per degree.

Post hoc multiple comparisons (p-values here are listed after the Bonferroni corrections (= 3 × p-value of the least significant differences).

*Amblyopic eyes versus fellow eyes: p < 0.0001. Amblyopic eyes versus control myopic eyes: p < 0.0001. No difference between control myopic and fellow eyes: p = 1.00.

†Amblyopic eyes versus fellow eyes: p < 0.0001. Amblyopic eyes versus control myopic eyes: p < 0.0001. No difference between control myopic and fellow eyes: p = 0.91.

‡Amblyopic eyes versus fellow eyes: p < 0.0001. Amblyopic eyes versus control myopic eyes: p < 0.0001. No difference between control myopic and fellow eyes: p = 1.00.

§Amblyopic eyes versus fellow eyes: p = 0.004. Amblyopic eyes versus control myopic eyes: p < 0.0001. No difference between control myopic and fellow eyes: p = 0.70.

Table 4. Log contrast sensitivity of the amblyopic (n = 20), fellow (n = 20) and control myopic (n = 16) eyes

analysis, after adjusting for age and race. The statistical results were the same as in the previous MANOVA analysis with all 20 amblyopic subjects.

The mean CSF values for the three groups (amblyopic, fellow and control myopic eyes) are shown in Figure 1. Compared to CSF of the fellow and control myopic eyes, the peak sensitivity of amblyopic eyes was shifted toward the lower spatial frequencies (around 2.7 cpd). IOD of logCS at the middle spatial frequencies (both 3 and 6 cpd) was statistically significantly correlated with the degree of anisometropia. However, there was no correlation at the higher (12 or 18 cpd) or lower (1.5 cpd) frequencies (Table 5).

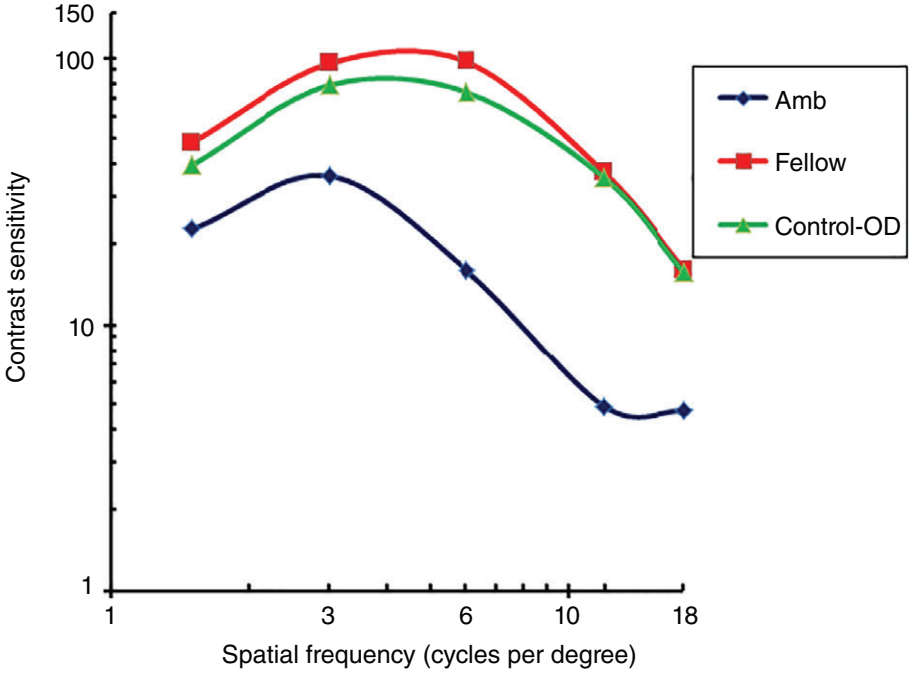

Figure 1. Mean contrast sensitivity of amblyopic eyes (n = 20), fellow eyes (n = 20), and control myopic eyes (n = 16, right eye only)

Discussion

CSF in amblyopic eyes has been extensively studied.[8,10,15,16,26–36] Reduced CSF has been reported in both anisometropic and strabismic amblyopia. However, the defect in CSF may be different in the two types of amblyopia.[10,15,26] CSF in strabismic amblyopia is reduced at high spatial frequencies, while in anisometropic amblyopia a depression of CSF over the whole frequency spectrum has been reported.[10,15,26]

Previous studies of anisometropic amblyopia focused purely on hyperopic anisometropia or included only one or two cases of myopic anisometropia in their analyses.[13,16,17] Bradley and Freeman[16] examined 10 amblyopic subjects: two subjects with myopic anisometropia, four with purely hyperopic anisometropia, and four with both strabismus and hyperopic anisometropia. They found that subjects with myopic anisometropia appeared to have reduced CSF at middle and high spatial frequencies but not at low frequencies. In contrast, subjects with hyperopic anisometropia appeared to have reduced CSF at all spatial frequencies.[16] However, upon further investigation the authors concluded that optical magnification differences between the two eyes (aniseikonia, measured using a

Correlation with degree of anisometropia	IOD of log contrast sensitivity 1.5 cpd	3 cpd	6 cpd	12 cpd	18 cpd
r-value	0.22	0.53	0.49	0.23	0.41
p-value	0.36	0.02†	0.03†	0.34	0.08

cpd: cycles per degree, IOD: interocular difference.
†Indicates statistical significance.

Table 5. Correlation between degree of anisometropia and interocular difference of log contrast sensitivity in amblyopic subjects (n = 20)

dichoptic size-matching task) caused a relative shift in the horizontal position of the CSF of the amblyopic eye with respect to the fellow eye. They concluded that in amblyopia resulting from either hyperopic or myopic anisometropia, there is reduced CSF at middle and high spatial frequencies but not at low frequencies (below 2 cpd), after adjusting for magnification differences using a mathematical model.[16]

The findings of this study concur with those of Bradley and Freeman. Although the absolute values of CSF in the amblyopic eyes might be impacted by minification, by including high myopic eyes with normal VA as controls, the difference identified between the amblyopic and control eyes reflected the effect of amblyopia, not minification, on CSF. Many other studies of hyperopic anisometropic amblyopia found that CSF was reduced at all frequencies,[10,13,14] which is inconsistent with the findings of Bradley and Freeman.

Early studies of hyperopic anisometropia did not include a control group with hyperopia but no amblyopia and did not adjust for the magnification difference induced by hyperopic anisometropia as Bradley and Freeman have reported.[10,13,14] Abrahamsson and Sjöstrand[15] were the first to include a control group in their study but they did not report the refractive error in the control group. Thus, it is unknown whether reduced CSF at all frequencies in hyperopic anisometropia is purely due to amblyopia or a combined effect of aniseikonia and amblyopia. A future study is warranted to determine the impact of amblyopia on CSF in subjects with hyperopic anisometropic amblyopia with a proper control group.

The effect of myopia on CSF has also been studied by several researchers.[37–39] Fiorentini and Maffei[38] measured CSF in eight subjects with bilateral myopia and two subjects with myopic anisometropia. Refractive errors ranged from −5.00 to −11.00 D (VA: 6/5 to 6/12) in the bilateral myopia group.[38] One of the two subjects with myopic anisometropia had unilateral amblyopia and the other had bilateral amblyopia.[38] The authors reported that CSF in subjects with bilateral myopia and no amblyopia was reduced at all frequencies and the peak of the CSF fell in the same spatial frequency range as in normal subjects.[38] CSF was measured, but not reported, in the one amblyopic eye associated with myopic anisometropia.[38] Interestingly, Fiorentini and Maffei[38] interpreted the CSF loss as consistent with an early retinopathy rather than myopia.

Oen et al.[39] tested CSF in subjects with refractive errors but no amblyopia, including nine hyperopes (+1.00 D to +5.00 D), 601 emmetropes (−1.00 D to +1.00 D), 82 mild myopes (−1.00 D to −2.00 D), 83 moderate myopes (−2.00 D to −5.00 D) and 32 severe myopes (< −5.00 D). The authors stated that CSF at 6, 12 and 18 cpd was statistically significantly associated with refractive error but there was no association at the lower frequencies.[39] Furthermore, they reported that subjects with severe myopia had lower CSF values (1.72, 1.99, 2.05, 1.81 and 1.36 at 1.5, 3, 6, 12 and 18 cpd) compared to emmetropes (1.77, 2.01, 2.12, 1.96 and 1.52, respectively).[39] The CSF reduction in severe myopia was 2.8, 1.0, 3.3, 7.7 and 10.5 per cent at 1.5, 3, 6, 12 and 18 cpd, respectively. Oen et al.[39] concluded that the CSF reduction associated with severe myopia was more prominent at the higher spatial frequencies.[39] In the present study, CSF reduction in amblyopic eyes was compared to fellow eyes and control eyes with bilateral high myopia but no amblyopia. The present findings indicate that amblyopia is the main cause of reduced CSF while myopia has a minor influence.

Sjöstrand[13] reported that patching improved CSF in both strabismic and anisometropic amblyopia. Only one of seven anisometropia subjects in his study had myopic anisometropia.[13] Amblyopia due to myopic anisometropia has been reported to have a poorer VA outcome after amblyopia treatment compared to amblyopia associated with hyperopic anisometropia.[40] On the other hand, the authors of this work have reported that both refractive correction and patching significantly improve the VA of amblyopic eyes associated with myopic anisometropia, with 88 per cent of subjects improving two lines or more.[19] A future study with a larger sample size is warranted to investigate whether amblyopia treatment improves reduced CSF in myopic anisometropic amblyopia.

Myopic amblyopia is rarely seen in the general population and therefore rarely reported. However, in the authors' clinic in Chicago, patients with myopic anisometropic amblyopia are regularly seen. In all cases the patients have unilateral high myopia and most are of African-American descent. The authors of this study are unaware of such clusters of high myopic amblyopia occurring elsewhere and deem it important that the vision of these patients is described. The authors intend investigating the family histories of these patients and to try to identify other such clusters.

There are a few limitations to this study. First, the control myopic group did not match the amblyopic subjects in age. Second, the goal was to enrol control subjects to match the magnitude of myopia in the amblyopic subjects. Enrolment of control subjects with myopia > −13 D was successful, as 15 subjects were enrolled to match our 15 amblyopic subjects. However, only one control subject was enrolled with myopia ≤ −13 D to match five amblyopic subjects with higher magnitudes of myopia. The clinical experience of the present authors indicates that bilateral amblyopia almost always accompanies such a high degree of myopia, so these subjects would not be qualified for this study. Third, several of the amblyopia subjects had a significant amount of astigmatism. The effect of astigmatism on CSF was not explored in this study. Finally, M&S Technologies may be the best CSF instrument available to clinics but it can truncate the range of the CSF values found. The basement effect is due to the tendency of a forced-choice staircase method to provide a low sensitivity threshold measurement even when a subject cannot see the gratings at all.

In summary, this is the first study to evaluate CSF specifically in myopic anisometropic amblyopia. Reduced CSF at middle and higher frequencies was found in amblyopic subjects with myopic anisometropia compared to the

fellow eyes of the same amblyopic subjects, as well as to eyes of myopic subjects without amblyopia. The peak CSF of amblyopic eyes was shifted toward the lower spatial frequencies. The decreased CSF at the middle spatial frequencies was associated with the degree of anisometropia. This study suggests that the effect of myopic anisometropia on CSF may be different from that of hyperopic anisometropia at the lower frequencies. A future study is needed to determine if the reduced CSF in eyes with myopic anisometropic amblyopia can be improved with amblyopia treatment.

ACKNOWLEDGEMENTS

This study was supported by the Illinois College of Optometry Research Fund and Illinois Society for the Prevention of Blindness. The authors would like to thank Drs Frank Thorn and Susan Kelly for their very helpful comments.

REFERENCES

1. von Noorden GK. *Binocular Vision and Ocular Motility. Theory and Management of Strabismus.*, 5th ed. St Louis: The CV Mosby Co, 1996. p. 216.
2. Attebo K, Mitchell P, Cumming R et al. Prevalence and causes of amblyopia in an adult population. *Ophthalmology* 1998; 105: 154–159.
3. Simons K. Preschool vision screening: rationale, methodology and outcome. *Surv Ophthalmol* 1996; 41: 3–30.
4. Repka MX, Cotter SA, Beck RW et al. A randomized trial of atropine regimens for treatment of moderate amblyopia in children. *Ophthalmology* 2004; 111: 2076–2085.
5. Holmes JM, Kraker RT, Beck RW et al. A randomized trial of prescribed patching regimens for treatment of severe amblyopia in children. *Ophthalmology* 2003; 110: 2075–2087.
6. Wallace DK, Edwards AR, Cotter SA et al. A randomized trial to evaluate 2 hours of daily patching for strabismic and anisometropic amblyopia in children. *Ophthalmology* 2006; 113: 904–912.
7. Scheiman MM, Hertle RW, Beck RW et al. Randomized trial of treatment of amblyopia in children aged 7 to 17 years. *Arch Ophthalmol* 2005; 123: 437–447.
8. Rydberg A, Han Y. Assessment of contrast sensitivity in children aged 3 years 9 months - 6 years with normal vision, visual impairment due to ocular disease and strabismic amblyopia. *Strabismus* 1999; 7: 79–95.
9. Rydberg A, Han Y, Lennerstrand G. A comparison between different contrast sensitivity tests in the detection of amblyopia. *Strabismus* 1997; 5: 167–184.
10. Campos EC, Prampolini ML, Gulli R. Contrast sensitivity differences between strabismic and anisometropic amblyopia: objective correlate by means of visual evoked responses. *Doc Ophthalmol* 1984; 58: 45–50.
11. Lourthai P, Bhurayanontachai P. Pattern of contrast sensitivity changes in acute central serous chorioretinopathy. *J Ophthalmol* 2017; 2017: 9053932.
12. Shandiz JH, Derakhshan A, Daneshyar A et al. Effect of cataract type and severity on visual acuity and contrast sensitivity. *J Ophthalmic Vis Res* 2011; 6: 26–31.
13. Sjostrand J. Contrast sensitivity in children with strabismic and anisometropic amblyopia. A study of the effect of treatment. *Acta Ophthalmol* 1981; 59: 25–34.
14. Hess RF, Howell ER. The threshold contrast sensitivity function in strabismic amblyopia: evidence for a two type classification. *Vision Res* 1977; 17: 1049–1055.
15. Abrahamsson M, Sjostrand J. Contrast sensitivity and acuity relationship in strabismic and anisometropic amblyopia. *Br J Ophthalmol* 1988; 72: 44–49.
16. Bradley A, Freeman RD. Contrast sensitivity in anisometropic amblyopia. *Invest Ophthalmol Vis Sci* 1981; 21: 467–476.
17. Hou F, Huang CB, Lesmes L et al. qCSF in clinical application: efficient characterization and classification of contrast sensitivity functions in amblyopia. *Invest Ophthalmol Vis Sci* 2010; 51: 5365–5377.
18. Pang Y, Goodfellow GW, Allison C et al. A prospective study of macular thickness in amblyopic children with unilateral high myopia. *Invest Ophthalmol Vis Sci* 2011; 52: 2444–2449.
19. Pang Y, Allison C, Frantz KA et al. A prospective pilot study of treatment outcomes for amblyopia associated with myopic anisometropia. *Arch Ophthalmol* 2012; 130: 579–584.
20. Pang Y, Frantz KA, Block S et al. Effect of amblyopia treatment on macular thickness in eyes with myopic anisometropic amblyopia. *Invest Ophthalmol Vis Sci* 2015; 56: 2677–2683.
21. Beck RW, Moke PS, Turpin AH et al. A computerized method of visual acuity testing: adaptation of the early treatment of diabetic retinopathy study testing protocol. *Am J Ophthalmol* 2003; 135: 194–205.
22. Moke PS, Turpin AH, Beck RW et al. Computerized method of visual acuity testing: adaptation of the amblyopia treatment study visual acuity testing protocol. *Am J Ophthalmol* 2001; 132: 903–909.
23. Repka MX, Beck RW, Holmes JM et al. A randomized trial of patching regimens for treatment of moderate amblyopia in children. *Arch Ophthalmol* 2003; 121: 603–611.
24. Repka MX, Kraker RT, Beck RW et al. A randomized trial of atropine vs patching for treatment of moderate amblyopia: follow-up at age 10 years. *Arch Ophthalmol* 2008; 126: 1039–1044.
25. Holmes JM, Beck RW, Repka MX et al. The amblyopia treatment study visual acuity testing protocol. *Arch Ophthalmol* 2001; 119: 1345–1353.
26. Hess RF, Li X, Lu G et al. The contrast dependence of the cortical fMRI deficit in amblyopia; a selective loss at higher contrasts. *Hum Brain Mapp* 2010; 31: 1233–1248.
27. Levi DM, McKee SP, Movshon JA. Visual deficits in anisometropia. *Vision Res* 2011; 51: 48–57.
28. Rogers GL, Bremer DL, Leguire LE. The contrast sensitivity function and childhood amblyopia. *Am J Ophthalmol* 1987; 104: 64–68.
29. Wali N, Leguire LE, Rogers GL et al. CSF interocular interactions in childhood amblyopia. *Optom Vis Sci* 1991; 68: 81–87.
30. Chung ST, Li RW, Levi DM. Identification of contrast-defined letters benefits from perceptual learning in adults with amblyopia. *Vision Res* 2006; 46: 3853–3861.
31. Kowal L. The contrast sensitivity function and childhood amblyopia. *Am J Ophthalmol* 1987; 104: 671–673.
32. Smith EL III, Harwerth RS, Crawford ML. Spatial contrast sensitivity deficits in monkeys produced by optically induced anisometropia. *Invest Ophthalmol Vis Sci* 1985; 26: 330–342.
33. Zele AJ, Pokorny J, Lee DY et al. Anisometropic amblyopia: spatial contrast sensitivity deficits in inferred magnocellular and parvocellular vision. *Invest Ophthalmol Vis Sci* 2007; 48: 3622–3631.
34. Repka MX, Kraker RT, Beck RW et al. Contrast sensitivity following amblyopia treatment in children. *Arch Ophthalmol* 2009; 127: 1225–1227.
35. Chatzistefanou KI, Theodossiadis GP, Damanakis AG et al. Contrast sensitivity in amblyopia: the fellow eye of untreated and successfully treated amblyopes. *J AAPOS* 2005; 9: 468–474.
36. Hou F, Huang CB, Tao L et al. Training in contrast detection improves motion perception of sinewave gratings in amblyopia. *Invest Ophthalmol Vis Sci* 2011; 52: 6501–6510.
37. Heng WJ, Oen FT, Peng CM. Effects of optical correction media on contrast sensitivity. *Ann Acad Med Singapore* 1997; 26: 18–21.
38. Fiorentini A, Maffei L. Spatial contrast sensitivity of myopic subjects. *Vision Res* 1976; 16: 437–438.
39. Oen FT, Lim TH, Chung MP. Contrast sensitivity in a large adult population. *Ann Acad Med Singapore* 1994; 23: 322–326.
40. Kutschke PJ, Scott WE, Keech RV. Anisometropic amblyopia. *Ophthalmology* 1991; 98: 258–263.