Regional Extent of Peripheral Suppression in Amblyopia

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PURPOSE. Previously, we have mapped amblyopic eye suppression within the central 20° of the visual field and observed a gradient of suppression that is strongest in central vision and weakens with increasing eccentricity. In this study, using a large dichoptic display, we extend our novel suppression mapping approach further into the periphery (from 20°–60°) to assess whether suppression continues to decline with eccentricity or plateaus.

METHODS. Sixteen participants with amblyopia (10 with strabismus, 6 with anisometropia without strabismus; mean age: 37.9 ± 11 years) and six normal observers (mean age: 28.3 ± 5 years) took part. The visual stimulus (60° diameter), viewed from 57 cm, was composed of four concentric annuli (5° radius) with alternate contrast polarities starting from an eccentricity of 10°. Each annulus was divided into eight sectors subtending 45° of visual angle. Participants adjusted the contrast of a single sector presented to the fellow eye to match the perceived contrast of the remaining stimulus elements that were presented to the amblyopic eye. A matching contrast that was lower in the fellow eye than the amblyopic eye indicated suppression.

RESULTS. Patients with strabismus exhibited significantly stronger interocular suppression than controls across all eccentricities (P = 0.01). Patients with anisometropia did not differ from controls (P = 0.58). Suppression varied significantly with eccentricity (P = 0.005) but this effect did not differ between patient groups (P = 0.217).

CONCLUSIONS. In amblyopia, suppression is present beyond the central 10° in patients with strabismus. Suppression becomes weaker at greater eccentricities and this may enable peripheral fusion that could be used by binocular treatment methods.

Keywords: amblyopia, suppression, periphery, strabismic amblyopia, binocular vision

Our views of the relationship between fusion, suppression, and diplopia are changing. It was once thought that patients with amblyopia did not possess fusional capabilities and so, as a consequence, suppression was needed to prevent diplopia in strabismic subjects.1 However, there is now ample evidence2–5 that many patients with amblyopia possess fusional capabilities that are not normally evident because of suppression. Therefore, if suppression is reduced, fusion rather than diplopia results. In the case of strabismus, this also requires either resolution of the motor deficit or anomalous retinal correspondence. The modern binocular approach to the treatment of amblyopia aims to re-establish binocular vision by strengthening fusion and consequently eliminating suppression. Recent studies have shown that the supervised use of binocular video games that use a rebalancing of contrast between the amblyopic eye and the fellow fixing eye (to strengthen fusion), improves visual acuity and stereopsis in patients with amblyopia.6–14 A more complete knowledge of suppression in amblyopia is needed to advance this treatment approach.

Previously, we have reported the depth and the gradient of suppression in the central 20° of the visual field in a group of patients with amblyopia (n = 14) caused by small angle strabismus or anisometropia.15 Suppression was present in all 14 of the patients tested and was particularly pronounced within the central 6° of the visual field. The region of strongest amblyopic eye suppression corresponded to the fovea of the fixing eye. Deeper suppression was also correlated with poorer amblyopic eye visual acuity.

Here, using similar methodology, we investigated amblyopic eye suppression in the peripheral visual field. Specifically, we tested the hypothesis that amblyopic eye suppression would be present in the peripheral visual field and that suppression would continue to decline with increasing eccentricity. We also assessed the relationship between the strength of peripheral suppression and amblyopic eye visual acuity. As in our previous study, we compared participants who had amblyopia due to strabismus with those that had anisometropic amblyopia without strabismus. The use of a stimulus presentation system with a wide field of view enabled us to include patients with large angles of strabismus (up to 30 prism diopters [PD]) who were excluded from our previous study of suppression in the central visual field.

Following our previous work, we measured suppression using a multifocal suprathreshold matching task. The technique is relatively fast to administer (~20 minutes) and provides quantitative information on the distribution of suppression in different regions of the visual field. This would be particularly useful in a clinical setting where one has to follow up on treatment strategies that target suppression reduction. An
understanding of the distribution of suppression in the periphery will also bear upon future treatment strategies that use peripheral fusion.

**METHODS**

**Participants**
The participants were recruited from the McGill Vision Research Unit at McGill University and the School of Optometry and Vision Sciences at the University of Waterloo. The study complied with the Declaration of Helsinki and ethics approvals were obtained from McGill University and the University of Waterloo.

Sixteen participants with amblyopia (mean age: 37.9 ± 11 years) and six healthy observers (mean age: 28.3 ± 5 years) took part (Table). Within the amblyopia group, 10 observers had amblyopia with strabismus (5 had exotropia, 3 esotropia, 1 microtropia, and 1 was orthotropic at the time of testing but had a history of strabismus surgery). Of these 10 observers, five also had anisometropia, and therefore were categorized as having mixed amblyopia. An additional six observers had pure anisometropic amblyopia without strabismus.

The normal observers had at least 20/20 vision in each eye, normal ocular motor function, and normal stereo acuity (<40 arc sec). The participants with amblyopia had a difference of at least 0.2 logMAR in visual acuity between the eyes and had impaired stereo acuity (>100 arc sec). Participants always wore the correct prescription (determined by objective and subjective refraction performed by an optometrist) either using their own spectacles or within a trial frame. The mapping of suppression was always conducted binocularly.

**Clinical Assessment**

Best-corrected monocular visual acuity was measured once using a commercially available, validated, computerized version of the Bailey Lovie logMAR chart presented on an iPad (Khyber Vision Japan LLC, Sendai, Miyagi, Japan). A letter-by-letter scoring procedure (0.02 score for each letter) was used and the termination criterion was five errors on a line. The chart was viewed from 4 m and all potential glare sources were removed.

Stereoacuity was measured with the Randot Preschool Stereo Acuity test (Stereo Optical Company, Chicago, IL, USA). This test provided a measurement range from 800 to 40 arc sec and was administered according to the manufacturer’s instructions.

The motor characteristics and magnitude of strabismus were determined using unilateral and alternating prism cover tests, respectively. Next, the Worth four dot test (W4D) and the Bagolini striated lens test were administered. These tests were conducted as in our previous investigation into central suppression. Briefly, both tests compare the subject’s percept of a stimulus that appears differently in each eye. In the case of the Worth 4 dot test, four lights (one white, two green, and one red) are viewed through tranaglyph (red – green) glasses where the white light is imaged in both eyes and red and green lights are differentially imaged between the eyes.

In the Bagolini lens test, a penlight is viewed through lenses with fine striations such that the light is perceived as oblique streaks at differing orientations between the eyes. In the case of binocular single vision, the two streaks will cross in the middle to form an “X.” In the case of strabismus with harmonious anomalous retinal correspondence, the two streaks will also cross in the middle to form an “X.” In the case of strabismus with unharmonious anomalous retinal correspondence or normal retinal correspondence, two streaks are seen but do not cross in the middle. In the case of suppression only one streak is seen or part of one streak is missing. The Worth 4 dot tests were conducted at distance (1.6 m) and near (35 cm) in a dark room. The Bagolini test was conducted at 1 m. The near Worth 4 dot test subtended 6̊ and the distance Worth 4 dot subtended 1̊ of visual angle. The results are shown in the Table and the results of both the tests were used for the interpretation of retinal correspondence. Discrepancy between the test results is common and was evident in our data. For example, for S6, diplopia was seen on the Worth 4 dot test, however suppression was noted on the Bagolini test.

Eye dominance was assessed in healthy observers using the Porta test. Participants were asked to place the thumb of one hand over the other and extend their arms fully. To determine the dominance, the participants had to align their thumbs to a 6 m target binocularly and report which eye was aligned to the target when viewing monocularly. The aligned eye was considered the dominant eye.

**Apparatus**

Stimuli were presented using a MacBook Pro laptop computer (Apple, Inc., Cupertino, CA, USA) running Matlab (Mathworks Ltd., Natick, MA, USA) and the Psychophysics Toolbox, Version 3.0.9. To achieve dichoptic presentation, we used a gamma-corrected LG three-dimensional (3D) cinema display (124 × 71 cm; Seoul, South Korea) viewed through polarized glasses. The luminance of the 3D screen was 150 cd/m2 for the midgray stimulus and 328 cd/m2 for the white stimulus when viewing the screen directly. These values fell to 61 and 135 cd/m2 when viewing through the polarized glasses. Each frame of the stimulus was computed as a single image with a resolution of 600 × 1600 pixels. This equipment is commercially available and suitable for use in the clinic.

**Mapping the Regional Extent of Suppression**

The procedure for mapping suppression in the periphery was identical to that used in our previous study of suppression in the central field. The mapping method (Fig. 1) was originally inspired by retinotopic mapping protocols used for functional magnetic resonance imaging studies. The visual stimulus (60° diameter), viewed from 57 cm, was composed of four concentric annuli (5° radius) with alternate contrast polarities starting from 10° eccentricity. Each annulus was divided into eight sectors subtending 45° of visual angle. In each trial, a sector from one annulus was presented to the fellow-fixing eye and the remaining sectors were presented to the amblyopic eye. All other annuli were presented to both eyes (Fig. 1). The sector presented to the fellow eye was of variable contrast. All other components of the stimuli were presented at 50% contrast. Stimulus contrast was reduced from the 80% value used in our previous study to ensure that crosstalk was minimized for the wide-field stimulus presentation system.

Before the mapping, the dichoptic images were aligned subjectively by moving the stimulus presented to the amblyopic eye using a computer keyboard. Polarized glasses were worn over refractive correction during the experimental task. Figure 2 shows an example of alignment by a participant with strabismic amblyopia.

Once alignment was complete, the measurement of suppression began. While fixating on a central black dot, participants adjusted the contrast of the sector shown to the fellow eye until it matched the perceived contrast of the remaining annulus that was presented to the amblyopic eye. There was no time constraint. The position of the sectors evolved in a predictable manner progressing from peripheral...
Mapping the Suppression in Periphery

RESULTS

Group suppression maps for the amblyopia with strabismus group, amblyopia without strabismus group, and healthy group are shown in Figure 5. Individual data are shown in Figure 4 (healthy group), Figure 5 (amblyopia with strabismus group), and Figure 6 (amblyopia without strabismus group). In the color-maps, the contrast mismatch is represented in a gradient fashion with red representing contrast underestimation (suppression), green representing contrast overestimation (facilitation), and yellow representing a perfect match (no suppression).

Suppression differed significantly between the three groups (significant main effect of group, F_{2,19} = 6.039, P = 0.009, Fig. 3). Post hoc Tukey analyses indicated that the amblyopia with strabismus group exhibited significantly stronger suppression than the healthy group (P = 0.010). Even though the amblyopia without strabismus group exhibited numerically stronger peripheral suppression than the normal group, this difference was not statistically significant (P = 0.579). Finally, the amblyopia without strabismus group did not differ from the amblyopia with strabismus group (P = 0.098).

There was also a significant main effect of eccentricity. The strength of suppression reduced significantly with increasing eccentricity (significant main effect of eccentricity, F_{4,77} = 3.149, P = 0.051) but this effect did not differ significantly between groups (no significant Group X eccentricity interaction, F_{6,57} = 0.847, P = 0.538). Post hoc Tukey tests revealed pairwise differences in suppression between the 10° and 15° eccentricity and the 25° and 30° eccentricity (P = 0.012). There were no other differences between any of the other tested eccentricities.

Considerable individual variability was evident within both the healthy and amblyopia groups; however, it is clear from Figures 4, 5, and 6, which show individual subject data for each group, that suppression was more pronounced in the amblyopia with strabismus group. In the healthy group, the presence of a stimulus can mask the detection of the stimulus in the other eye. This phenomenon is known as dichoptic masking and it reflects inhibitory dichoptic interactions. In the six healthy participants, the variations seen in the sectors are an example of such dichoptic masking resulting from pairwise comparisons, and therefore P values reported are corrected for multiple comparisons.
contralateral inhibitory signals from each eye prior to binocular summation. It is evident that these interactions, although they are not large, can occur in the periphery beyond the central 10° of the visual field.

The region of the amblyopic eye corresponding to the fovea of the fellow eye is indicated with an asterisk in Figure 5 for patients in the amblyopia with strabismus group. Each of these corresponding points fell within the central 20° of the visual field, and therefore was not coincident with the peripheral suppression mapping stimulus used in this study.

For the participants with amblyopia (data from both amblyopia groups combined), interocular visual acuity difference was not significantly correlated with the average strength of suppression at any eccentricity. The data were also analyzed separately for each group (Fig. 7). There was no significant correlation for the amblyopia with strabismus group (open circles, gray line) at any of the eccentricities (−0.06; P = 0.85 [10°–15°], −0.35; P = 0.31 [15°–20°], −0.21; P = 0.55 [20°–25°], −0.12; P = 0.73 [25°–30°]). There was a significant correlation between suppression strength and visual acuity difference at the 10° to 15° eccentricity for the amblyopia without strabismus group (closed circles, black line). Correlations for the other eccentricities did not reach statistical significance although the 15° to 20° eccentricity showed borderline significance (−0.83; P = 0.04 [10°–15°], −0.76; P = 0.07 [15°–20°], −0.34; P = 0.50 [20°–25°], −0.77; P = −0.07 [25°–30°]).

A comparison between the peripheral suppression mapping data reported here and our earlier central suppression mapping data suggested that suppression tended to reduce exponentially with increasing eccentricity until 6° to 8° at which point suppression reduced more gradually (Fig. 8).

The average matching contrast ratio between the amblyopic and fellow eyes was between 1.8 and 1.4 at 15° to 30° of eccentricity as is seen in Figure 8. Three (amblyopia with strabismus group) of 16 tested subjects showed contrast ratios greater than 5.

The data from the previous study were obtained from a different group of participants using virtual reality goggles that only allowed for mapping of central vision (E Magin Z100, New York, NY, USA). In this study we used a LG Cinema 3D display in conjunction with polarized glasses that provided the necessary field of view for peripheral suppression mapping. Therefore, the comparison of these results should be interpreted with caution, although the trend clearly indicates reduced suppression with increasing eccentricity.

**DISCUSSION**

We report evidence of peripheral visual field suppression (10°–30°) in patients with amblyopia. In agreement with our previous study of central vision (0°–10°),15 there was a gradient of amblyopic eye suppression, whereby suppression
was weaker at greater eccentricities. However, the magnitude of the change in suppression with increasing eccentricity was small compared with our previous measures of central vision.

Patients with amblyopia and strabismus exhibited significantly stronger peripheral suppression than controls and a nonsignificant trend for stronger peripheral suppression than the amblyopia without strabismus patients. However, the amblyopia without strabismus group did not differ significantly from the healthy group suggesting weak or absent peripheral suppression. This is contrary to previous reports where peripheral suppression was present in anisometropic amblyopia. This discrepancy may be due to considerable interindividual variability in measures of suppression. For example, in our dataset, A2 does not show suppression, whereas A4 shows regional suppression in the periphery.

A qualitative comparison with our previously published central suppression data suggested that suppression is weaker in the periphery of the amblyopic eye and that the strength of suppression reaches a plateau at approximately 6° to 8° of eccentricity. However, this comparison should be interpreted with caution as different groups of patients participated in the two studies and there were methodologic differences between the two studies, as described above.

Six participants within the amblyopia with strabismus group (e.g., S2, S3, S4, S8, S9, S10) exhibited only regional suppression of the periphery, whereas four other participants (S1, S5, S6, S7) showed measurable suppression across the entire field tested. In both esotropia and exotropia, the maximum overlap of the deviated eye visual field with the fellow fixing eye visual field occurs in the nasal hemifield.
FIGURE 5. Individual data for the amblyopia with strabismus group presented as described in Figure 3. Participants S1, S2, and S3 had esotropia, S4, S5, S6, and S7 had exotropia, S8 had a microtropia, S9 had prior history of strabismus surgery, and S10 had an intermittent exotropia with anisometropia. The region marked with an asterisk (*) represents the fellow fovea relative to the position of the amblyopic eye fovea when the participant subjectively aligned the suppression mapping annuli. This alignment may have been influenced by anomalous retinal correspondence.
Therefore, the nasal hemifield may be subject to maximum suppression to avoid visual confusion/diplopia. In agreement with this idea, three participants with strabismus exhibited regional nasal hemifield peripheral suppression (2 with esotropia [S2, S3], 1 with exotropia [S4]). Nasotemporal asymmetry was not evident in our earlier work investigating central suppression. Unfortunately, the small number of patients with regional suppression in the current study precluded a formal analysis of hemifield specific suppression.

The data for patients who had amblyopia without strabismus varied considerably across individuals, although on average this group did not differ significantly from the healthy group. Three patients in this group exhibited regional suppression (A1, A4, A5). Previous results relating to peripheral suppression in amblyopia are mixed. Joose and colleagues\(^2\) found that suppression within a 25° binocular field ranged from total suppression to nasal hemifield suppression in four patients with constant exotropia and amblyopia. They also found peripheral suppression in 11 patients with exotropia but no amblyopia. However, in the case of microstrabismus with esotropia\(^2\), they only found suppression in 5 of 14 subjects tested and the regional extent of suppression ranged from 5° to 30°. Their measurements were much more punctate than ours.

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**Figure 6.** Individual data for the amblyopia without strabismus group (anisometropic amblyopia) presented as described in Figure 3.
and relied on very accurate eye alignment, which might account for some of the differences.

Economides et al.,25 in their investigation of target acquisition using saccades in a 60° field, found that constant and intermittent exotropia (with no amblyopia) was associated with suppression of the nasal hemifield (temporal retina) of each eye. The acquisition of targets in the visual field with saccades matched with perceptual suppression maps that were measured separately. However, the suppression maps were obtained in an all or nothing fashion, meaning that only suppression or no suppression was indicated. The depth of suppression was not significantly correlated with interocular acuity difference in this group of patients ($P > 0.05$) when considering the group as a whole.

Sireteanu and Fronius21 tested suppression within a 40° binocular field and found pronounced peripheral suppression in patients with amblyopia. Suppression extended up to 30° into the periphery of the temporal visual field in patients with esotropic strabismic amblyopia with maximum suppression occurring at 7° to 12° of eccentricity. However, the spatial extent of suppression in the nasal visual field was less pronounced for these patients, extending to approximately...

**Figure 7.** The relationship between interocular visual acuity difference in logMAR (AME–FFE) and the depth of suppression (average fellow eye matching contrast) for the amblyopia group from 10° to 30° eccentricity. Larger values on the y-axis indicate weaker suppression and larger values on the x-axis indicate deeper amblyopia. Open circles represent data from the amblyopia with strabismus group and closed circles represent data from the amblyopia without strabismus group. The gray lines represent the correlation fits for amblyopia with strabismus group and the black line represent the correlation fits for amblyopia without strabismus group. Peripheral suppression was not significantly correlated with interocular acuity difference in this group of patients ($P > 0.05$) when considering the group as a whole.

**Figure 8.** Previously published group mean central suppression mapping data from a different group of patients ($n = 14$) are depicted in the left panel. The group mean peripheral suppression mapping data ($n = 16$) are depicted in the right panel. Suppression is quantified as the contrast ratio between the AME and the FFE. A ratio is used because different base contrasts were used in the two experiments due to differing stimulus display apparatus. Larger contrast ratios indicate stronger amblyopic eye suppression. A contrast ratio of 1 signifies no suppression. Suppression reduces rapidly from central vision to 6° of eccentricity and then exhibits a more gradual reduction with increasing eccentricity. The relationship is fit with an exponential function for both data sets (central mapping: $y = 7.916e^{-0.164x}$; $R^2 = 0.980$, $P < 0.001$. peripheral mapping: $y = 2.196e^{-0.018x}$; $R^2 = 0.94$, $P = 0.03$).
### Clinical Characteristics of Participants With Amblyopia

<table>
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<tr>
<th>Observer</th>
<th>Age/Sex</th>
<th>Type</th>
<th>Refraction</th>
<th>Acuity</th>
<th>Stereo &amp; Suppression</th>
<th>Retinal Correspondence</th>
<th>History</th>
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<tbody>
<tr>
<td>S1</td>
<td>35 y/F</td>
<td>Strabismus: right constant esotropia 8 PD</td>
<td>RE: none</td>
<td>RE logMAR = 0.4; 20/50 (6/15)</td>
<td>Stereo: none</td>
<td>Harmonious ARC with central suppression</td>
<td>Detected at 5 y of age No surgery Patching for more than 8 hr/d for several mo</td>
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<tr>
<td>S2</td>
<td>50 y/M</td>
<td>Mixed constant left esotropia 12 PD</td>
<td>RE: −1.00 D−/−0.75 DC × 30</td>
<td>RE logMAR 0.00; 20/20 (6/6)</td>
<td>Stereo: none</td>
<td>Harmonious ARC with central suppression</td>
<td>Detected at 11 y of age No surgery No patching Eye exercise 1−2 y Glasses since 12 y of age</td>
</tr>
<tr>
<td>S3</td>
<td>59 y/F</td>
<td>Mixed constant right esotropia 8 PD</td>
<td>RE: +6.00 D</td>
<td>RE logMAR 0.5; 20/63 (6/19)</td>
<td>Stereo: none</td>
<td>Harmonious ARC</td>
<td>Detected at 12 y of age No surgery Daily patching for 6 mo</td>
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<tr>
<td>S4</td>
<td>31 y/F</td>
<td>Strabismus: right constant exotropia 4 PD (distance), ortho (near)</td>
<td>RE: plano/−0.50 DC × 90</td>
<td>RE logMAR: 0.2; 20/50 (6/15)</td>
<td>Stereo: fusion (distance and near) RE Bagolini: fusion</td>
<td>Suppression</td>
<td>Strabismus surgery at 4 and 6 y of age No patching</td>
</tr>
<tr>
<td>S5</td>
<td>33 y/M</td>
<td>Mixed left constant exotropia 20 PD</td>
<td>RE: −1.5 D</td>
<td>RE logMAR: 0.2; 20/13 (6/4.2)</td>
<td>Stereo: none</td>
<td>Harmonious ARC</td>
<td>Detected before 3 y of age 2 surgeries Patching until 7 y of age</td>
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<td>23 y/F</td>
<td>Hypertropia: 6 PD</td>
<td>RE: plano</td>
<td>RE logMAR 0.7; 20/60 (6/5.0)</td>
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<td>Strabismus surgery at 18 mo Glasses from 2 y of age Patching from 4 to 7 y</td>
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<td>42 y/M</td>
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<td>RE logMAR: 0.2; 20/50 (6/15)</td>
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<td>Detected at 16 y of age Patching for 1 y for 4 hr/d No surgery</td>
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<td>Mixed anisometropia intermittent esotropia 4 PD (near), ortho (distance)</td>
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<td>RE logMAR 0.5; 20/65 (6/19)</td>
<td>Stereo: 100 arc secs</td>
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<tr>
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<td>Type</td>
<td>Refraction</td>
<td>Acuity</td>
<td>History</td>
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<td>27 y/M</td>
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10° of eccentricity. Patients with anisometropic amblyopia also exhibited peripheral suppression, but without a nasotemporal asymmetry. Similarly Pratt-Johnson and Tillson also reported suppression affecting the whole binocular field in patients with strabismic amblyopia.

In contrast, Barrett et al. reported an absence of suppression in the patients with strabismic amblyopia that they tested. In 70% (7/10) of their subjects, there was a total absence of suppression and in 150% (3/10), a very weak amount of suppression was found in the 50° binocular field that they tested. This might be accounted for by their methods as the fellow eye was only subjected to mean luminance stimulation. Suppression is a contrast dependent phenomenon that is maximal when the fixing eye sees patterned stimuli, as is the case in natural viewing conditions.

The different methods used to elicit suppression may explain the variability in findings relating to suppression. Use of flashed stimuli, for example, may tend toward absence of suppression. However, when natural viewing conditions are simulated, there is a greater chance of suppression. In our study, we had the ability to change the contrast of the segment presented to the fellow-fixing eye while also showing other patterned regions to this eye. This manipulation provided an opportunity to simultaneously elicit and quantify suppression, but the extent to which the measurements relate to suppression occurring under other types of viewing conditions is not known.

Our data suggest that the depth of suppression is still affected by eccentricity in the far periphery but that suppression is weak. Unlike central suppression, the strength of peripheral suppression was not consistently correlated with the amblyopic eye acuity loss. Specifically, no significant correlations between visual acuity difference and strength of suppression were found for any eccentricity when all patients were included in the analyses. Separate analyses for each group revealed no significant correlations for the amblyopia with strabismus group. However, the amblyopia without strabismus group exhibited a significant correlation for the 10° to 15° eccentricity and nonsignificant trends for correlations at further eccentricities. This raises the possibility that the relationship between acuity and peripheral suppression may differ between the two types of amblyopia. In general, the rate of decline in suppression strength with increasing eccentricity varied considerably across participants. This variability may have weakened any relationship between visual acuity and suppression strength in the periphery.

Similarly, a systematic relationship between stereopsis and peripheral suppression was not evident in our data, however only 5 of 16 participants had measurable stereopsis (100 or 200 arc sec; A3, A5, A7, S8, S10). Some participants with peripheral suppression (e.g., S10) exhibited stereopsis, whereas others with no peripheral suppression (e.g., A6) did not.

Our study has some limitations. The central 20° was stimulated with a mean luminance background, and therefore it is possible that the absence of patterned stimulation in this region might affect the suppression maps obtained, although there is evidence that, in some cases, measurable suppression can be elicited by a mean luminance background. The 25° to 30° eccentric ring was not flanked on the outer side of the tested location and similarly, the closest ring to the center (10°-15°) had no flanking ring on the inner side. This may also have influenced the suppression maps. Finally, the anomalous fixation position in some of those that had ARC was not accounted for, although the error produced by this is small relative to the eccentricities studied here (MD: 8.7°, SD: 6°). Except for S6 and S7, most of the participants had minor deviations of less than 7° at the viewing distance used for suppression mapping.

The suppression maps were obtained based on the subjective alignments made by the participants to simulate natural viewing conditions as much as possible. Most of our patients had mild amblyopia, and therefore it is possible that those with dense amblyopia might show stronger peripheral suppression. Also, within the suppression maps we ‘find stray’ isolated sectors of deep (red) suppression directly flanked (either radially or concentrically) by regions exhibiting negligible (yellow) suppression, or even facilitation (green) in some cases (Figs. 5, 6). This likely reflects noise in the measurements.

Weaker peripheral suppression in the amblyopic eye could explain the differing results seen with the Worth 4 dot and Bagolini tests (Table). In the case of strabismus, images of these two tests would fall on peripheral retinal loci in the strabismic eye where suppression is weaker. In some cases (see also Table 1 in our earlier study) the conclusion of ARC is determined by these tests. While the origin of this percept remains unclear, resulting foveal suppression found in dichoptic measures would argue against the assumed etiology of ARC where the fovea of the strabismic eye changes its retinal correspondence to allow a nonfoveal point to have the same correspondence as the fovea of the non strabismic eye. In other words, central suppression and peripheral ARC may coexist. This is consistent with the results of Sireteanu who found evidence that when changes in correspondence occurred in some strabisms they were only in peripheral locations. Central regions were resistant to such changes. Following this logic, clinical findings of ARC may not present the impediment to the restoration of binocular vision as once thought. Another interesting finding was a good concordance between the Bagolini test and the suppression mapping. Observers with only central intermit-tent suppression or fusion in the Bagolini test (Table: S1–S4, S8, S9, A1–A6) showed less peripheral suppression (Figs. 5, 6) compared with those with complete Bagolini suppression (S5–S7).

The matching contrast ratio between the ambyopic and fellow eyes used to quantify the suppression indicated weaker suppression in the periphery (<2). However, 3 of 16 subjects, showed stronger suppression (>5), but this did not show a clear relationship with the angle of strabismus. It is quite likely that peripheral fusion is possible when only minimal interocular contrast differences exist. This potential for peripheral fusion could be used by future amblyopia treatments to promote recovery of binocular vision.

Acknowledgments

The authors thank the anonymous reviewers for valuable suggestions during the peer review process.

Supported by Canadian Institutes of Health Research (CIHR) Grant MOP #108188 (RFH; Ottawa, ON, Canada), Natural Sciences and Engineering Research Council (NSERC) Discovery Grant # 115079 (BT; Ottawa, ON, Canada), and CIHR Grant # 122105 (BT).

Disclosure: R.J. Babu, None; S. Clavagner, None; W.R. Bobier, None; B. Thompson, None; R.F. Hess, None

References
