Anisometropic Amblyopia: Spatial Contrast Sensitivity Deficits in Inferred Magnocellular and Parvocellular Vision

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PURPOSE. To measure achromatic spatial contrast sensitivity in patients with anisometropic amblyopia under conditions favoring inferred parvocellular (PC) or magnocellular (MC) pathway mediation.

METHODS. Fourteen anisometropic amblyopes (VA amblyopic eye 6/12 or lower; better eye greater than 6/7.5) and 10 age-matched, nonamphotic controls (VA 6/6) participated. Foveal spatial contrast sensitivity was measured using localized, spatially narrow band targets (0.25–8.0 cpd) presented in the center of a steady pedestal (favoring MC detection) or a pulsed pedestal (favoring PC detection) that was set within a uniform surround.

RESULTS. Spatial contrast sensitivity functions were handpass for the steady-pedestal and lowpass for the pulsed-pedestal. Under steady-pedestal adaptation, the amblyopes showed reduced spatial contrast sensitivity at intermediate frequencies (1–2 cpd), consistent with MC sensitivity loss. For the pulsed-pedestal condition, a generalized loss of sensitivity was observed across all spatial frequencies (0.5–4 cpd), consistent with PC sensitivity loss. The magnitudes of inferred MC and PC loss were similar. In the steady- and pulsed-pedestal paradigms, results for the better eye of greater than 75% of the amblyopes were normal or near normal at low and intermediate spatial frequencies.

CONCLUSIONS. Anisometropic amblyopia produces spatial contrast sensitivity losses in inferred PC- and MC-mediated vision, suggesting there may be abnormal processing of MC and PC signals in higher visual areas, including those with orientation and spatial frequency selective cells in the visual cortex. With spatially localized stimuli and a paradigm designed to distinguish between MC and PC vision under conditions that differ only in the interstimulus adaptation, the better eye of the amblyopes was normal or near normal. (Invest Ophthalmol Vis Sci. 2007;48:3622–3631) DOI:10.1167/iovs.06-1207

Amblyopia is a developmental disorder resulting from anomalous binocular visual input early in life. It is commonly associated with visual deprivation, anisometropia (unequal refractive errors in the two eyes), or strabismus (eye misalignment).1 Patients with amblyopia show reduced visual acuity in one or both eyes, in the absence of overt ocular disease; that cannot be improved by refractive correction. Although amblyopia is primarily a deficit in spatial visual acuity, its defects are also evident in spatial localization, fixation, ocular motility, accommodation, crowding effects, attention behavior, motion, and temporal processing.2

Contrast encoding within the primate visual system is predominantly mediated by two processing streams with different response properties: the magnocellular (MC) and the parvocellular (PC) streams. Characterized at the level of the retina and lateral geniculate nucleus (LGN), the MC pathway has high-contrast gain and saturates at relatively low levels of contrast, whereas the PC pathway has lower contrast gain and a more linear contrast response function.3–5 The MC pathway is thought to be involved in the detection and discrimination of briefly presented, achromatic patterns of low contrast, whereas the roles of the PC pathway are primarily thought to include high spatial frequency visual resolution, chromatic processing, and achromatic processing.6,7

In amblyopia, contrast sensitivity is traditionally found to be normal or near normal at low spatial frequencies but reduced at high spatial frequencies.8–13 The reduction of high spatial frequency contrast sensitivity, or visual acuity, would be considered a PC pathway deficit. However, more recent spatial contrast sensitivity studies have shown that though some amblyopes have reduced contrast sensitivity at the high spatial frequencies only,8,12,14,15 others have deficits of sensitivity at all spatial frequencies.8–11,16,17 It has been suggested that loss of sensitivity confined only to the high spatial frequencies represents damage to the PC pathway only, and the overall loss at all spatial frequencies represents loss in MC and PC pathways.18 Spatial contrast sensitivity losses imply that cortical orientation- and spatial frequency-selective cells are affected in amblyopia, but whether specific retinogeniculate pathways are involved must be clarified.

The purpose of the present study was to evaluate the spatial contrast sensitivity deficits of patients with amblyopia using recently introduced psychophysical paradigms to separate spatial contrast sensitivity responses based on the inferred MC and PC pathways.19,20 In previous studies, these spatial contrast sensitivity paradigms were successful in characterizing deficits in patients with melanoma-associated retinopathy,21 and retinitis pigmentosa.22 A feature of the paradigms is that the stimulus presentations are identical for the conditions favoring MC and PC mediation; the only difference is in pre- and post-adaptation. This is important in that we look for potential differences in sensitivity for stimuli of identical spatial composition. Studies that separate MC and PC function with stimuli of different
spatial frequency content (see, for example, Davis\textsuperscript{23} and Shan\textsuperscript{24}) cannot yield unambiguous mechanistic interpretation in the presence of a spatial frequency-dependent deficit.

The data in this report show that amblyopia produces spatial contrast sensitivity deficits in both the MC and the PC pathways in the anisometric eye that are accompanied by little or no deficit in the better eye.

**Patients and Methods**

**Patients**

A group of 14 anisometropic amblyopes (age range, 8–31 years; mean, 13.8 years; SD, 6.6 years) and 10 control observers (age range, 9–26 years; mean, 14.6 years; SD, 6.2 years) were recruited through the Illinois College of Optometry. The Institutional Research Board at the University of Chicago and the Illinois College of Optometry approved all experimental procedures and participants gave informed consent in accordance with the Declaration of Helsinki. All participants underwent a comprehensive eye examination before the experimental participation.

Inclusion criteria for the anisometric amblyopes were as follows: Patients had a difference in refractive error between the eyes of 1 Diopter or more and visual acuity of 6/12 or worse in the amblyopic eye. High contrast visual acuity was measured with the Snellen chart\textsuperscript{25} using the patient’s best optical correction at 6 m. Binocular vision was evaluated with ophthalmoscopy. No observers exhibited nystagmus. Dilated fundus examination revealed no ocular abnormality. Patient’s best optical correction at 6 m. Binocular vision was evaluated in the presence of a spatial frequency–dependent deficit.

**Stimuli**

Examples of the spatially localized stimuli are illustrated in Figure 1A, which shows that the spatial frequency of the test patch increased from left to right. The stimulus was defined by a sixth spatial derivative of a Gaussian (D6) in one direction\textsuperscript{27} and a Gaussian in the orthogonal direction. The spatial frequency bandwidth is approximately one octave at half height.\textsuperscript{19} The space constant of the orthogonal Gaussian was a constant proportion of the peak spatial frequency.\textsuperscript{21} The maximum positive contrast occurs in the center of the D6 pattern. The stimulus duration was 53.2 ms (four refreshes). The contrast, C, of the D6 pattern was defined as

$$C = \frac{I_{\text{peak}} - I_{\text{pedestal}}}{I_{\text{pedestal}}}.$$  

where $I_{\text{peak}}$ refers to the maximum luminance of the D6 pattern, and $I_{\text{pedestal}}$ refers to the luminance of the pedestal on which it was presented.\textsuperscript{19}

The D6 test target, presented in the center of a square $12.5 \text{ cd} \cdot \text{m}^{-2}$ luminance pedestal that subtended $7.6^\circ$ on a side, was located in the center of the $25 \text{ cd} \cdot \text{m}^{-2}$ steady adapting field ($10.5^\circ \times 9.1^\circ$). The pedestal produced a 0.3-log unit luminance decrement relative to the adapting field (illustrated in Fig. 1B). The remainder of the screen (vertical bars with a width of $0.6^\circ$ to either side of the adapting field) was set to $20 \text{ cd} \cdot \text{m}^{-2}$ (80% of the adapting field luminance). Four thin black diagonal lines that extended from the edges of the pedestal to a region just outside the D6 pattern guided fixation.

**Rationale for the Approach**

There were two stimulus presentation paradigms, a steady-pedestal paradigm (Fig. 1B) intended to favor the MC pathway and a pulsed-pedestal paradigm (Fig. 1C) intended to favor the PC pathway.\textsuperscript{28} The rationale is that the MC and PC pathways exhibit different contrast gain properties. Contrast gain refers to how rapidly a response changes with changes in contrast and is characterized by the slope of the contrast/response function. At the level of the retina and lateral geniculate nucleus (LGN), the MC pathway has a high-contrast gain and saturates at low levels of contrast, whereas the PC pathway has a more linear contrast response function.\textsuperscript{5–6,25} The rationale for the psychophysical separation of MC and PC pathway function was originally developed by Pokorny and Smith\textsuperscript{25} to characterize mediation of luminance contrast discrimination by the PC and MC pathways. The stimulus array, four squares with small separations, was identical in the pulsed and the steady-pedestal paradigms; the paradigms differed only in the

<table>
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| *Anisometropia and strabismus. |
interstimulus adaptation. One square was designated to be the test on each trial and was incremented or decremented relative to the other three. In the pulsed-pedestal paradigm, the four-square stimulus array appeared as a contrast change, with an additional increment or decrement in the test square. In this case, the pulsed-pedestal introduced a large spatiotemporal contrast change that was intended to saturate the MC pathway. Thus discrimination in the pulsed-pedestal paradigm was inferred to be mediated by the PC pathway. In the steady-pedestal paradigm, the four-square stimulus array was displayed continuously. Only the test square was incremented or decremented during the trial. With brief pulsed stimuli, discrimination in the steady-pedestal paradigm was inferred to be mediated by the MC pathway. Assignment of PC or MC mediation was based on contrast gain measurements and differences in temporal and spatial summation for the two paradigms. The effects of spatial, temporal, and spatiotemporal contrast on discrimination can be isolated with appropriate modification of the spatial parameters, as demonstrated with chromatic stimuli mediated by the PC pathway.28

To study spatial contrast sensitivity, the four-square array used in the previous work was replaced by narrow-band, spatially localized test patterns of various spatial frequencies superimposed on a large uniform pedestal.19 The spatial pattern was the sixth derivative of a Gaussian or D6.27 This pattern has a one-octave spatial frequency bandwidth and a local appearance in space (Fig. 1A). For the pulsed-pedestal paradigm, the temporal step in contrast change was controlled by an abrupt change of large pedestal was designed to decrease sensitivity of the entire population of MC cells, revealing activity in the PC pathway (Fig. 1C). With the use of a large pedestal for the steady-pedestal paradigm, PC and MC pathways could adapt to the pedestal retinal illuminance (Fig. 1B). Leonova et al.19 manipulated temporal parameters to bias sensitivity of the pathways. First they biased the steady-pedestal paradigm detection to the MC pathway by using a brief pulse. They also biased the detection to the PC pathway by using a stimulus with gradual onset and offset, a raised temporal cosine to eliminate temporal transients at onset and offset. Here, the steady- and pulsed-pedestal paradigms yielded identical contrast sensitivity functions indicating a common underlying mechanism, interpreted as the PC pathway mediation. From these data, it could be inferred that for the steady-pedestal paradigm, lower spatial frequency thresholds were MC pathway mediated whereas higher spatial frequency thresholds were PC pathway mediated. Thus, PC pathway mediation is inferred at all spatial frequencies for the pulsed-pedestal paradigm, and MC pathway mediation is inferred at lower spatial frequencies for the steady-pedestal paradigm.

Psychophysical Procedure

Detection thresholds were estimated with a double-random alternating staircase with a three-yes one-no decision rule. Either a horizontal or a vertical D6 pattern was presented in each trial. One staircase measured thresholds for a vertical D6 pattern and the other for the horizontal D6 pattern. The observer was required to identify the orientation of the D6 pattern as a correct response. No feedback was given. An easily discriminable test contrast was presented on the first trial, and the step size was halved in subsequent trials until a criterion step of 0.0015 log units was attained. Staircases continued without further change in step size.
size once the criterion step size was reached. Staircases terminated after 10 reversals at the criterion step size for both staircases, and the average of the last six reversals of each of the two staircases was taken as the threshold measure.

**Testing Procedure**

The procedure for measuring spatial contrast sensitivity was explained, and observers were given a brief practice series with the steady- and pulsed-pedestal paradigms. Stimuli were viewed monocularly with the natural pupil through the best optical correction. The nontested eye was occluded with an opaque eye patch. The observer first adapted for 2 minutes to the steady field, followed by a 30-second adaptation period that preceded each test condition. The observer initiated each trial by pressing a button on a response pad (GamePad; Gravis, San Mateo, CA). The stimulus was presented after a brief warning tone. The observer's task was to judge whether the D6 pattern was vertical or horizontal (2-alternative forced choice) and to record the response by pressing the corresponding button on the response pad. The order of conditions was fixed at 1, 0.5, 2, 4, 0.25, and 8 cycles per degree (cpd). Within each condition, the order of the steady- and pulsed-pedestal paradigms was randomized. Thus there were 12 testing conditions within an experimental session (six spatial frequencies, two paradigms each).

**Spatial Contrast Sensitivity Functions**

The spatial contrast sensitivity functions were described using an exponential function of the form,

\[ s(f) = A f^n \exp(-pf) \]

where \( A \) is the scaling parameter, \( f \) is the spatial frequency (cpd), \( n \) is an exponent, and \( p \) is the high-frequency roll off. The equation was fitted to the individual observer data for each condition by minimizing the sum-of-square differences between the data and the three free parameters.

**RESULTS**

A one-way ANOVA between the left and right eyes of the control observers showed no significant difference \((P > 0.05)\). There were no systematic within-observer differences between contrast thresholds for the horizontal and vertical stimulus orientations, and the two thresholds were averaged. Figures 2 and 3 show contrast sensitivity (mean of the vertical and horizontal D6 patterns) as a function of spatial frequency (cpd) for the steady- and pulsed-pedestal paradigms, respectively. In
Each figure, the average data for the normal control observers are given on the left (Cont 1–10); average data for the anisometropic amblyopes are given on the right (Amb 1–14). The solid gray line in each panel of Figures 2 and 3 indicates the lower boundary of the 95% confidence limits of the control observers. The solid black line in each panel shows the best-fitting solution of the exponential spatial contrast sensitivity function.

The right panels of Figures 2 and 3 show the spatial contrast sensitivity functions for the amblyopes (_filled symbols, amblyopic eye; unfilled symbols, better eye). It is apparent that the amblyopic eye (filled symbols) shows reduced contrast sensitivity compared with the better eye with high spatial frequency roll-off. For most patients, at most spatial frequencies, the better eye is within the lower boundary of the 95% confidence limits of the control group. There are greater levels of variability in the patient group when compared to the control observers. We present the results of the analyses of the spatial contrast sensitivity functions to establish the pattern of spatial frequency losses in the amblyopic patients and to identify whether the contrast sensitivity deficits are MC or PC vision specific.

To examine whether patients with amblyopia showed preferential deficits in spatial contrast sensitivity under test conditions that favored MC or PC pathway mediation, we examined the log ratios of the contrast sensitivities (visuograms) for the steady- and pulsed-pedestal paradigms for each patient. The magnitude of the contrast sensitivity deficit in the amblyopic eye relative to the better eye of the same patient for the steady- and pulsed-pedestal paradigms (left and right panels, respectively) is shown in the Figure 4 visuograms. The dashed line indicates equal thresholds for the two eyes (zero on the ordinate). Individual symbols represent each observer (see legend), and the filled gray circles show the group mean (±1 SD). Amblyopic eyes show reduced contrast sensitivity at all frequencies compared with better eyes. A binomial test with equal probability of the amblyopic eye with similar contrast sensitivity to the better eye indicated that at 0.5 cpd (left panel), there was a 3% chance of 11 of the 14 amblyopic eyes showing reduced contrast sensitivity (below the zero line). Obviously, chance probabilities at the other spatial frequencies would be lower. Individual observers show varying degrees of contrast sensitivity loss. Overall, the patterns of loss for the steady- and pulsed-pedestal paradigms are similar. Although there appears to be a slight trend for larger losses at higher spatial frequencies, this trend is not significant ($P > 0.05$). This implies there is a nonselective loss of spatial contrast sensitivity in the amblyopic patients for the range of spatial frequencies tested. In the left panel (steady-pedestal), the data for 4 cpd are inferred to be detected by the PC pathway (as in Leonova et al.\textsuperscript{15}) and correspond closely with the same 4 cpd data from the pulsed-pedestal paradigm (right panel). This demonstrates the internal data consistency between the two paradigms.

Are the nonselective, spatial frequency contrast sensitivity deficits greater for inferred MC or PC vision? The data in Figure 5 represent the difference in log contrast sensitivity for each
patient’s amblyopic eye for the steady- and pulsed-pedestal paradigms. The horizontal dashed line (zero on the ordinate) indicates equal reduction in contrast sensitivity in the two pathways. Although the trends in the individual data might suggest that contrast sensitivity losses are similar for the steady- and pulsed-pedestal paradigms at 0.25 and 0.5 cpd and larger for the steady-pedestal paradigm 1.0 and 2.0 cpd, the means for each group (filled gray circles) are not different from zero for any spatial frequency. Therefore, we conclude that the amblyopic spatial contrast sensitivity deficit is nonselective for MC- or PC-mediated vision.

Did the individual observers show a correlation between the relative MC- and PC-mediated visual sensitivities? Results of a Spearman correlation indicated there was not a significant association between contrast sensitivity of the amblyopic eye and the LogMAR value of the amblyopic eye (not shown). To determine the association between spatial contrast sensitivity in the MC and PC pathways in each of the groups (left column, amblyopic eye; middle column, better eye; right column, control observers), the panels in Figure 6 show the relation between contrast sensitivity for the steady-pedestal (inferred MC) and pulsed-pedestal (inferred PC) paradigms at each spatial frequency. For the amblyopic eyes (left column), the regression slope was not significantly different from zero ($r^2 = 0.07$; $P < 0.05$) at 0.25 cpd. However, for spatial frequencies between 0.5 and 2.0 cpd, the association between MC and PC spatial contrast sensitivity was significant (0.5 cpd: $r^2 = 0.37$; $P < 0.05$; 1.0 cpd: $r^2 = 0.85$; $F_{1,11} = 29.38$; $P < 0.0002$; 2.0 cpd: $r^2 = 0.79$; $F_{1,11} = 21.40$; $P < 0.0007$). The better eyes of the amblyopes (middle column) showed a significant association between MC and PC contrast sensitivity at 0.25 cpd ($r^2 = 0.53$; $F_{1,12} = 6.22$; $P < 0.02$), whereas at higher spatial frequencies, the slope of the regression line was not significantly different from zero (0.5 cpd: $r^2 = 0.36$; 1.0 cpd: $r^2 = 0.52$; 2.0 cpd: $r^2 = 0.49$). For the control observers (right column), there was a significant association between MC and PC contrast sensitivity at 0.25 cpd ($r^2 = 0.71$; $F_{1,8} = 6.76$; $P = 0.03$), 1.0 cpd ($r^2 = 0.65$; $F_{1,8} = 6.52$; $P = 0.03$), and 2.0 cpd ($r^2 = 0.77$; $F_{1,8} = 6.89$; $P = 0.03$), but not at 0.5 cpd ($r^2 = 0.71$; $F_{1,8} = 4.645$; $P = 0.06$). Comparison of the slope of the regression line for each group (amblyopic eyes, better eyes, and control) at each spatial frequency showed that the confidence limits of the slopes of each group overlapped, indicating that association between MC and PC contrast sensitivity in each group was similar. The data in each of the panels in Figure 6 and the results of the Spearman correlations and regression lines indicate that the association between MC- and PC-mediated spatial contrast sensitivity was comparable for both pathways at all spatial frequencies, irrespective of the rate of contrast sensitivity change between pathways for a specific spatial frequency. Spatial contrast sensitivity for the control observers was clustered about similar contrast sensitivity values and exhibited the highest contrast sensitivity. The better eyes of the amblyopes showed trends similar to those of the control group, particularly at 1.0 and 2.0 cpd. The amblyopic eyes, while showing a similar pattern of association between MC and PC contrast sensitivity when compared to the control group and their better eyes, had reduced contrast sensitivity. The correlations for the 4 and 8 cpd data were not presented because contrast sensitivity was determined by the PC pathway in both paradigms. In all cases, unmeasurable values were not included in the analyses.

**Discussion**

Using a psychophysical paradigm designed to isolate MC and PC pathway vision at low to intermediate spatial frequencies, it is demonstrated that (1) anisometropic amblyopia produced MC- and PC-mediated spatial contrast sensitivity losses, (2) the reduction in contrast sensitivity was nonselective for the range of spatial frequencies evaluated (0.25–8.0 cpd), and (3) the
better eyes of the amblyopes were normal or near normal at all spatial frequencies (0.25–8.0 cpd).

Amblyopic spatial contrast sensitivity deficits were evident, to differing degrees for each observer, at all spatial frequencies (0.25–4.0 cpd) for inferred MC- and PC-mediated vision (Fig. 4). The psychophysical paradigm separates MC and PC retinogeniculate pathway responses based on their different contrast gain properties, but thresholds also engage higher order orientation and spatial frequency–selective cells. The human psychophysical data represent an upper envelope of a population of receptive fields varying in size and sensitivity. The thresholds, however, do not resemble single cell data of macaque retinal ganglion cells because single cell data show band-pass characteristics. Thus, although the psychophysical data are consistent with activation of a given inferred retinal pathway (MC or PC), postretinal processing plays a significant role in determining psychophysical sensitivity. The results suggest there may be anomalous processing of MC and PC signals in higher visual areas, including those with orientation and spatial frequency–selective cells in the visual cortex.

MC- and PC-mediated visual function has been previously evaluated in amblyopic patients using paradigms that bias detection to one or the other pathway by manipulation of the chromatic, achromatic, or spatiotemporal characteristics of the stimulus. Bradley et al. measured color and luminance spatial contrast sensitivity functions (0.25–8.0 cpd) and observed spatial frequency–specific color and luminance discrimination deficits in five of their six patients. More recently, studies using pattern visual evoked potentials (VEPs), functional magnetic resonance imaging (fMRI), and positron emission tomography (PET) have demonstrated that the visual response to stimuli of low temporal frequency and high spatial frequencies are reduced in amblyopia. These data were inferred to indicate the presence of a parvocellular deficit. Consistent with these observations, the motion onset VEP, the source of which is in the extrastriate motion-sensitive area and presumably

**Figure 6.** Correlation between log contrast sensitivity of inferred MC vision (steady-pedestal paradigm) as a function of log contrast sensitivity of inferred PC vision (pulsed-pedestal paradigm). The left column shows the data for the amblyopic eyes, the middle column shows the better eyes of the amblyopes, and the right column shows the data for the control observers. Each row represents a different spatial frequency, as indicated in each panel. The symbols for the amblyopic observers are consistent with those in Figures 4 and 5. The regression line is shown in each panel.
derived from cells in the MC pathway, is relatively normal in amblyopes, as is the global integration of local motion direction signals. There may, however, be differences in form and motion processing because evidence shows that motion detection and discrimination thresholds for second-order, contrast-defined stimuli might be reduced in patients with amblyopia. These observations have been supported by results from a motion discrimination study in primates that produced amblyopia with optical defocus (anisometropia) or surgical transection of the lateral rectus muscle (strabismus). The literature shows evidence of MC and PC pathway sensitivity loss using different stimulus conditions, but these studies often observe deficits in only one or the other pathway for their experimental conditions.

What are potential explanations for the present study identifying nonselective MC- and PC-mediated spatial contrast sensitivity deficits in anisometropic amblyopia? Differences between the results of this study and past studies may be attributed to our evaluation of MC and PC vision using a paradigm that separates the pathways based on their contrast gain and adaptation characteristics. Previous investigations have consistently demonstrated selective high spatial frequency losses; however, these investigations did not specifically evaluate MC- and PC-mediated vision; the spatial contrast sensitivity functions therefore represented the upper specific envelope of the underlying spatial frequency-selective filters. Relative weightings of the two pathways depend on the spatial, temporal, and chromatic characteristics of the stimuli and on the adaptation level. Differences in the results of the current work and the VEP and imaging studies are still to be reconciled. Neural generators of the psychophysical thresholds and evoked potentials are likely to be different. Furthermore, contrast sensitivity deficits observed at threshold do not necessarily indicate the presence of supathreshold deficits. A potential source of disparity in the results of current and past studies may be attributable to the type and severity of the amblyopia. In primate models of amblyopia, however, a wide range of cell sensitivities has been tested on all response dimensions (e.g., spatial, temporal, orientation, and binocular organization), and clear, consistent interocular differences have been observed between normal and amblyopic monkeys in all but the mildest amblyopes. Studies in animals with experimentally induced amblyopia show a loss of cortical binocularity and a shift in cortical dominance away from the affected eye. Although controversy existed over whether the site of the amblyopic deficit is retinal or cortical, current opinion holds that the principal site for the neural deficit in amblyopia is in the striate visual cortex (area V1). It is unclear whether the observed changes in the retinogeniculate pathway are secondary to influences from the cortex. Reports of dysfunction at the level of the LGN in animal studies of amblyopia are conflicting. Evidence shows that there is degradation in PC neurons from the affected eye and that the spatial and temporal properties of LGN cells of amblyopic monkeys are normal. Differences may be specific to the species studied, the technique for the induction of amblyopia, or methodological issues. Even though selective loss of LGN PC cells observed in animal studies using lid suture are consistent with the PC pathway deficits found in evoked potential and imaging studies in humans, it might be possible that after lid suture, the diffuse spectrally attenuated light stimulus that reaches the retina may be sufficient to stimulate MC cells sensitive to low-contrast, transient changes in light level. However, this may not provide a sufficient stimulus for PC cells and might lead to the observed selective PC cell sensitivity loss.

For test conditions not specifically designed to bias to the MC or the PC pathways, human spatial contrast sensitivity functions may be roughly considered in terms of the frame-work introduced earlier, such that high spatial frequencies are mediated by the PC pathway and low spatial frequencies by the MC pathway. For anisometropic and strabismic amblyopes, the spatial contrast sensitivity literature is inconsistent, with evidence for selective (MC or PC) and nonselective (MC and PC) losses in both groups. In anisometropic amblyopia, psychophysical data variously demonstrate selective high spatial frequency contrast-sensitivity losses or nonselective losses across all spatial frequencies. Recent fMRI studies show either low or high spatial frequency losses. Not unlike the anisometropic literature, there is evidence for both high spatial frequency and for nonselective spatial frequency losses in strabismic amblyopes, with fMRI data showing low spatial frequency deficits. What is consistent between the two classes of amblyopes is that the magnitude of contrast sensitivity loss increases with increases in the depth of the deficit; however, it should be noted that in some cases spatial contrast sensitivity deficits are not observed.

The better eyes of the amblyopic patients in this study were normal or near normal for the spatial frequency range tested for inferred MC and PC vision. Previous work has shown that the better eyes of amblyopic patients exhibit reduced contrast sensitivity at high spatial frequencies (beyond those tested in this study) with normal or near-normal spatial contrast sensitivity at low spatial frequencies (less than approximately 6 cpd). Our use of spatially localized stimuli may play an important role here. Amblyopes are known to exhibit deficits in contrast sensitivity for targets flanked by distracter stimuli. For example, visual acuity measured with high-contrast optotypes is lower when measured with a multiple letter chart compared with a single letter. This crowding effect is thought to be due to a combination of contour interaction, fixational eye movements, and attentional factors. Spatial contrast sensitivity is abnormal when evaluated with multiperiod sinusoidal gratings and high spatial frequency orientation discrimination is reduced when evaluated using large field gratings that reduce the effects of eccentric fixation. The use of narrow-band, localized D6 test stimuli might have minimized the crowding effect.

An important distinction between this and previous work is that the test paradigm is designed to differentiate between MC and PC vision using identical, localized test stimuli and conditions that differ only in the pre- and post-adaptation. The temporal properties of the stimulus presentation bias detection to the different pathways and the spatial frequency of the localized test stimuli are the same. Our data demonstrate that persons with anisometropic amblyopia have reduced spatial contrast sensitivity in visual pathways mediating magnocellular and parvocellular vision and that the better eyes of the amblyopes are normal or near normal for the range of spatial frequencies tested.

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References


