Contrast Thresholds for Sine Gratings of Children with Amblyopia

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Contrast threshold functions were measured on 26 amblyopic children before and after minimal occlusion therapy. On initial presentation the relative contrast sensitivity deficit the amblyopic eye was in every case much less than that predicted from the deficit in visual acuity for letters. In fact, in seven of the children the contrast sensitivity functions for the amblyopic and fellow nonamblyopic eye were indistinguishable despite the expression of substantial amblyopia on letter charts. Only four children exhibited a substantial contrast sensitive loss in the amblyopic eye with a cut-off spatial frequency below 30 cycles/degree. The majority of children who showed deficits in contrast sensitivity did so only at medium and high spatial frequencies. On the basis of these findings it appears that measurements of contrast thresholds for single sinusoidal gratings do not probe fully the deficits of spatial resolution in amblyopia. Finally, among the few children who exhibited a sizeable initial deficit, only two showed obvious improvement in contrast sensitivity in response to minimal occlusion therapy. Invest Ophthalmol Vis Sci 24:782–787, 1983

Measurements of contrast sensitivity functions in amblyopia associated with either strabismus or anisometropia usually reveal deficits for gratings of high spatial frequency but deficits at low spatial frequencies appear to be less common.1–5 Previous studies conducted on relatively small numbers of adult amblyopes suggest that the deficits in contrast sensitivity are considerably less than might be expected on the basis of their visual acuity for letters. Virtually all such measurements have been made on adult amblyopes but the nature of the deficits in children is less well documented. Accordingly, as part of a controlled clinical trial of a new treatment6 for amblyopia described in previous papers,7,8 measurements were made of the contrast threshold functions for sine gratings in 26 children (6–14 years of age) with strabismic or anisometropic amblyopia. In this paper the contrast threshold functions and grating acuities measured before and after treatment are compared with the visual acuities measured on letter charts.

Materials and Methods

Contrast thresholds for vertical sinusoidal gratings were measured using a specially constructed large screen, high luminance, high resolution, flicker-free, video display.9 The screen size was 400 × 300 mm, having white colour (P4) with a frame refresh rate of 100 HZ and a 2000 line vertical raster scan. The mean luminance of the screen was 150 cd/m², which is considerably higher than that used in most other studies reported in the literature. This results in a higher spatial frequency resolution limit because visual acuity is luminance dependent up to at least 200 cd/m² for normal observers.10 The video screen was masked by a surround screen 1.5 × 1.5 m matched for luminance and color. Viewing distances of 1.14 m and 5.7 m were used to enable spatial frequencies to be measured between 0.25 and 50 cycles/degree. After demonstrating the appearance of the grating to the child, the contrast was increased slowly from below threshold until the child reported when the grating was first visible. The measurement was repeated until three consistent responses were obtained. The value was checked quickly by a “seen-not-seen” sequence, switching between grating and a blank screen and again by reducing the contrast from above threshold to the point of disappearance. However, the latter technique was not used routinely because of the risk of obtaining high thresholds due to adaptation to the suprathreshold stimulus. Each child was tested separately and alternately for each spatial frequency using a simple opaque occluder.

Each child was tested both before and after six weeks amblyopia treatment sessions.7,8 Thirteen children received treatment with rotating gratings and an equal number (the control group) viewed a gray disc for similar periods of time while they performed intensive competitive visuomotor tasks for 12 min.
Prior to this treatment session the nonamblyopic eye was occluded for a short period of time for various tests of visual function described earlier. Fourteen of the 26 children manifested a strabismus that was associated with anisometropia in nine cases. Eleven of the remaining 12 children had anisometropia of between 1 and 4 diopters (D) while the 12th was simply amblyopic in one eye. Three of the 14 children with strabismus had received surgical treatment several years previously.

Results

On initial presentation seven of the 26 children showed no evidence whatsoever of a contrast sensitivity deficit in the amblyopic eye. In each of these cases the amblyopic and fellow eye contrast sensitivity functions were similar to the point of being virtually indistinguishable, yet the letter acuities of the amblyopic eye as measured on a test chart varied between 6/19 and 6/9.5. Fourteen children showed only a small deficit in contrast sensitivity in the amblyopic eye, but even so, the cut-off spatial frequency in all cases was 30 cycles/degree or better (2 min per cycle or 1 min stripe width), which is mathematically equivalent to 6/6 in Snellen notation. The latter measure (grating acuity) was determined from the contrast sensitivity functions by extrapolating the data for high spatial frequencies to a contrast sensitivity of 1.0. Only five of the children exhibited a substantial sensitivity loss in the amblyopic eye that resulted in an extrapolated grating acuity of less than 30 cycles/degrees.

A contrast sensitivity function of one of the seven children that showed no contrast sensitivity deficit in the amblyopic eye is illustrated in Figure 1A. The general shape of the contrast sensitivity functions for the two eyes were comparable to those of a normal adult subject. Six of these children manifested a strabismus, while the seventh suffered from only a slight anisometropia. Representative contrast sensitivity functions from the group of 14 children with mild deficits are displayed in Figures 1B–D. For the majority of these children the deficits were apparent only at high spatial frequencies as illustrated by the subject of Figure 1B. However, in two children (Figs. 1C, D) the deficit was somewhat more pronounced at medium spatial frequencies between 1 and 10 cycles/degree. The contrast sensitivity functions from the four patients that showed the severest deficits are illustrated in Figures 2 and 3. Two of these patients (WO and SA) showed no response to treatment (Fig. 2) and had dense amblyopia (letter acuity between 6/60) associated with anisometropia and strabismus that had been treated surgically. The other two patients showed some improvement with treatment (Fig. 3). One of these (GS) was both anisometropic and strabismic and was severely amblyopic (visual acuity 3/60), while the other (AH) was anisometropic (R + 2.00; L. piano) and possessed only a mild amblyopia in the right eye that had a letter acuity of 6/12. In both of these cases the amblyopic deficit was still significant at the lowest spatial frequency tested (0.25 cycles/degree).

In order to demonstrate better the poor correspondence between the performance on letter charts and on grating patterns, an estimate of the grating acuity of the amblyopic eye was derived from the contrast sensitivity function of each of the 26 children. The grating acuities (cut-off spatial frequency) were derived by extrapolating each contrast sensitivity curve to the abscissa that corresponds to a grating with a contrast of 1.0. The grating and letter acuities of the amblyopic eye of each of the 26 children are shown by the filled symbols in Figure 4 where the line at 45° represents identical performance (defined by equality of the angular subtense of the bars of the gratings with the limbs of the letters) on the two tasks. Comparable data from the fellow nonamblyopic eyes were also derived for each child and are depicted by open symbols. Without exception, the performance of the amblyopic eye with gratings was substantially superior to that on letter charts. By contrast, the letter and grating acuities of the nonamblyopic eyes were virtually identical, although some subjects manifested slightly better acuity for grating. These points are emphasized further by Figure 5 in which the ratio of the grating acuities of the amblyopic and nonamblyopic eye of each subject are plotted against the ratio of their letter acuities. In every case the grating acuity ratio was much higher than the corresponding ratio of the letter acuity of the two eyes. For all but six subjects the grating acuity ratios lay between 0.8 and 1.0, reflecting the close similarity of the grating acuities of the two eyes of most subjects. By contrast, however, the respective letter acuity ratios of these subjects were substantially lower.

While there was no obvious correlation between the magnitude of the deficits in contrast sensitivity and the type and magnitude of the amblyopia, it may be significant that the severest contrast sensitivity deficits were usually found in children that possessed both a strabismus and anisometropia. Three of the five children with the severest contrast sensitivity losses fell into this category. Although the sample size was very small, four of the five children that possessed only a strabismus (without any accompanying anisometropia) exhibited no deficits in contrast sensitivity with the amblyopic eye. The fifth child in this category manifested only a very slight deficit. Thus,
there were indications that contrast sensitivity losses were most common among children with anisometropia, particularly when accompanied by strabismus.

Overall the nonamblyopic eye was occluded for about 1/2 hr on each of the six weekly visits to allow for various tests of the visual function of the amblyopic eye as well as the 12-min treatment session. Although on the average children from both groups showed a measurably significant improvement²,³ (about 0.15 of units) in their letter acuities, in only two of the 26 children was there a significant improvement in the contrast sensitivities of the amblyopic eye. Both children were from the gray control group and had a relatively severe initial sensitivity deficit (Fig. 3). The improvement in letter acuity with treatment for these two children was just slightly larger (0.2 log units) than that of the mean of the sample as a whole.

**Discussion**

The most significant finding to emerge from this study was the relatively minor nature of the differences between the contrast sensitivity functions of the amblyopic and fellow nonamblyopic eyes of the majority of the 26 amblyopic children examined. Indeed, for seven children the contrast sensitivity functions of the two eyes were indistinguishable, and 14 others exhibited only a very slight contrast sensitivity loss in their amblyopic eye, and usually only for high spatial frequencies. Only five of the 26 children exhibited a substantial contrast sensitivity loss in the amblyopic eye.
Fig. 2. Threshold contrast sensitivity for sine-wave gratings as a function of spatial frequency for both eyes of two amblyopic children who exhibited a significant contrast sensitivity deficit which did not respond to treatment. ○ ○: amblyopic eye, before treatment; ● ●: amblyopic eye, after treatment; □ □: nonamblyopic eye, before treatment; ■ ■: nonamblyopic eye, after treatment. Both subjects (WO, 14 yrs; SA, 7 yrs) manifested a strabismus with significant anisometropia of 5 D. WO viewed rotating gratings during treatment, while SA was from the control group.

Fig. 3. Threshold contrast sensitivity for sine-wave gratings as a function of spatial frequency for both eyes of two amblyopic children who exhibited a significant contrast sensitivity deficit on initial testing but which improved significantly following six treatment sessions. Symbols as in Figure 2. AH (10 yrs) possessed a moderate degree of anisometropia (2 D, right eye), and a relatively mild amblyopia. The acuity of the amblyopic eye was 6/12 as measured on a letter chart prior to treatment and 6/9.5 afterward. GS (10 yrs, left eye) manifested a severe esotropia and anisometropia. The letter acuity of the amblyopic eye was less than 6/120 prior to treatment and only 6/96 afterward. The latter received treatment with gratings while AH was from the control group.
Fig. 4. The relationship between grating acuity (ordinate) and Snellen letter acuity (abscissa) for the amblyopic (filled symbols) and nonamblyopic (open symbols) eyes of all 26 amblyopic children. The solid line represents equivalent performance on the two tests of visual acuity (equal angular subtense of the individual bars of the grating and the limbs and spaces of the letters). Snellen letter acuity was measured on a chart that was characterized by an equal number of letters (5) in each row and only a regular logarithmic scaling (in 0.1 log unit steps) of both the size and spacing of the letters on each line as well as the separation between lines.

Fig. 5. The relationship between the ratio of the grating acuity (amblyopic/non-amblyopic) of the two eyes of each subject (ordinate) and the ratio of their letter acuities (abscissa). The line at 45° represents equivalent acuity ratios for the two tests of visual performance.

Eye, but even in these cases the grating acuities were still much better than would be anticipated on the basis of their performance on letter charts. For example, the grating acuity of the two children (WO and GS) with the severest contrast sensitivity deficits were about 10 cycles/degree (6 min/cycle or 3 min stripe width), which is mathematically equivalent to 6/18 in Snellen notation. By contrast, the visual acuities assessed on letter charts were below 6/120. Although a similar lack of correspondence between the performance of amblyopes on letter charts and gratings can be observed in earlier data, it has rarely been expressly commented upon and usually only on the basis of results from a small sample of amblyopes. Our measurements on a relatively large group of amblyopes illustrate the generality of this observation. Thus, it appears that measurements of the contrast thresholds for single sine gratings do not probe the full deficit of spatial resolution in amblyopia. A similar conclusion has been drawn earlier from measurement of the visual acuity for single letters. Characteristically amblyopes manifest significantly better acuity for letters presented in isolation than for letters presented in rows, a finding that may relate to spatial interaction effects or to unstable eye movement control. Together, these various findings suggest that the recognition tasks that are the most disturbed in amblyopia are those that require the strict maintenance of spatial relationships for correct identification. More simple tests of spatial resolution, that require the subject to distinguish a pattern from a homogeneous field without the need to recognize the nature of the pattern, are affected far less.

Of the children with strabismus (including those with anisometropia as well), only one (GS, Fig. 3) could be considered as an example of the second class of contrast sensitivity deficit as described by Hess and Howell. The seven other children with strabismic amblyopia that exhibited deficits in contrast sensitivity did so only at high spatial frequencies. This raises the possibility that deficits in contrast sensitivity at low spatial frequencies may not be manifest in young children with strabismic amblyopia and only become so in older children at or beyond the upper extreme of the age range that we examined. A similar conclusion can be drawn from comparison of the results of two earlier investigations.

In view of earlier claims for improvement in contrast sensitivity as well as letter acuity in response to minimal occlusion therapy, measurements were made of the contrast sensitivity functions on completion of the six treatment sessions. However, since initially only a handful of subjects showed significant deficits in contrast sensitivity, it was not possible to pursue in detail questions relating to the effectiveness of the treatment. Only two of the four subjects (from the control group) with substantial contrast sensitivity loss showed noticeable improvement with treatment.
But, as with the gains in letter acuity, it was not possible to identify those aspects of the treatment that were responsible for this improvement.

**Key words:** amblyopia, strabismus, contrast sensitivity, visual acuity, gratings, grating acuity, anisometropia

**References**


