Acuity of Amblyopic Children For Small Field Gratings and Recognition Stimuli

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Tests of grating acuity often underestimate amblyopia and underrefer esotropic infants with a fixation preference. To evaluate the effect of the large grating field used in preferential looking (PL) procedures, an eight-alternative, small field (about 1°) grating acuity test was devised. Gratings contained at least eight cycles. Thirty-seven strabismic and/or anisometropic amblyopes, ages 3–13 yr, were tested. In most amblyopic eyes, grating acuities were better than recognition acuities; the difference was reduced, however, in the small field test compared to the large field (6°) test (means, 1 oct vs. 1.6 oct; paired-t = 5.5, $P < .001$). Nevertheless, the same relation between grating and recognition acuities occurred for small as for large fields: an increased discrepancy between grating and recognition acuities accompanied poorer acuity. This larger discrepancy is attributed to increased probability summation of amblyopic eyes for low spatial frequencies. For preschool children who can be tested by both procedures, the eight-alternative grating acuity test may be preferable to operant PL because it is more easily administered and materials are simpler. **Invest Ophthalmol Vis Sci 27:1148–1153, 1986**

Resolution acuities assessed with gratings or contrast sensitivity often underestimate amblyopia when compared to recognition (Snellen) acuities.[1–6] And, in esotropic infants with a fixation preference, grating acuities may not indicate amblyopia.[7,8] One explanation for these phenomena is the large stimulus size of gratings. Grating fields have typically subtended 6–12°, whereas the largest letters on a standard Snellen chart subtend 0.8° (20/200) to 1.7° (20/400). In infants, extrafoveal retina may mediate detection of the large field gratings.[9] If the advantage of peripheral retina for detection of grating stimuli could be minimized, perhaps by reducing field size, the effect of amblyopia on central vision might be more effectively assessed. The present study compared acuity for gratings containing at least eight cycles in small and large fields to acuity for recognition targets of 37 amblyopic children, ages 3–13 yr.

Materials and Methods

Small Field, Eight-Alternative Grating Acuity Test

Eight circular fields containing high contrast (nominally 83%), vertical, black and white square-wave gratings were arranged in two rows on a 16 × 23 gray card. The space-averaged luminance of the small field cards was approximately 1.2 log cd/m^2. Each card contained a test grating and seven "blanks"; each blank was a high spatial frequency grating (0.006 cm/half-cycle) that was below threshold at the test distance (100 cm for adults, 50–75 cm for children with normal eyes). Test gratings ranged from 0.01–0.15 cm/half-cycle in intervals of about 0.3 oct. Grating field diameter was 0.7 cm for gratings 0.04 cm/half-cycle and smaller; field diameter increased with half-cycle widths larger than 0.04 cm to maintain eight grating cycles (maximum diameter 2.2 cm). The number of cycles in the small field test grating was about eight for amblyopic eyes with 20/75 or poorer grating acuity and 10 or more for eyes with 20/70 or better acuity.

Test cards were presented at a 35–100 cm distance, depending upon the subject's age and vision status. A fixed test distance was maintained ±3 cm, and, if necessary, the examiner's hand was placed lightly on the child's head to control the test distance. The visual angle of the small grating fields for the 37 amblyopic eyes ranged from 0.4° (0.7 cm diameter at 100 cm) to 3.6° (2.2 cm diameter at 35 cm) with a median of 1.2°. For eight children with normal eyes, the small grating fields subtended a median of 1° in diameter (range 0.7–1.2). The eight grating fields were numbered so that older subjects could report the number of the test grating. Young children touched the grating with a "magic wand" (toy on a stick).

Test spatial frequencies were presented until the following occurred: 2/2 or 2/3 correct responses ("pass")

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Table 1. Patient information

	Refractive status (diopters)			
	*Amblyopic eye**		*Anisometropia†*	
Diagnosis	*Median*	*Range*	*Median*	*Range*
Anisometropia (22)				
Myopia (17)	−9.0	−2.9–−20.0	7.3	1.75–14.25
Hyperopia (5)	+5.5	+4.0–+11.0	2.5	1.00–8.00
Strabismus (15)				
(Esotropia 14, exotropia 1)				
With anisometropia (8)				
Myopia (1)	−3.4	—	2.1	—
Hyperopia (7)	+2.25	+2.0–+3.75	1.75	1.00–2.25
Without anisometropia (7)				
Myopia (2)	−2.4	−0.6–−3.0	—	—
Hyperopia (5)	+2.4	+0.75–+5.9	—	—

* Spherical equivalent (S.E.) † S.E. or cylinder, whichever was larger

on one test grating and 0/2 or 1/3 correct responses ("fail") on a higher spatial frequency grating. Acuity was scored as the highest spatial frequency grating passed. The sequential binomial probability of passing or failing a given spatial frequency occurring by chance alone is less than 0.03. Testing each subject required less than 10 min.

Large field grating acuities were obtained using the operant PL apparatus and the staircase estimation procedure described previously.[10] Grating fields subtended a median diameter of 6.1° (range 4.6–8.2; test distance 54–100 cm). The space-averaged luminance of the gratings and surround was 2.0 log cd/m^2. Testing each subject required 15–20 min.

In children ages 3 yr and older, the error of acuity estimation for the staircase procedure using a stepsize of 0.5 oct is about 0.3 oct.[4] The error of acuity estimation for the small field procedure has not been derived directly, but may be similar due to the small step size (0.3 oct). Acuity of the non-amblyopic eye of eight amblyopic children retested after intervals of 1–3 months varied a median 0.1 oct (range 0–0.7).

Recognition acuity tests included Snellen letter charts (A-O Project-O-Chart) (27 patients), the "E game" (6 patients) and the Allen picture cards (9 patients). Twenty-eight patients (76%) were tested with single recognition targets (often due to their poor acuity) and nine were tested with line letters. The space-averaged luminance of recognition targets was approximately 1.1–1.5 log cd/m^2. Recognition target areas were an average of 66% smaller than the small field grating areas; differences ranged between 80% smaller grating area than recognition target area up to 200% smaller recognition than grating target area.

Absolute acuities were analyzed in terms of visual angle (min arc=Snellen denominator/20 and min arc/one-half grating cycle). To control for differences between absolute acuities of each test, the interocular acuity difference (IAD) was also analyzed.[7,8]

Subjects

Before testing, all subjects and their parents were informed of the test procedures and gave voluntary consent. Subjects with normal eyes—eight children, ages 2 yr 8 months–6 yr 7 months (median 3 yr 8 months), and seven adults, ages 23–45 yr—were tested by both grating acuity tests with their best optical correction. All were emmetropic or mildly myopic.

Thirty-seven patients, ages 3 yr 3 months–13 yr (median 7 yr 2 months), were tested; each patient had a difference between acuities of each eye of two Snellen lines or an IAD of 0.6 oct or more. All patients were tested with their best optical correction. Each patient was followed regularly and, within several months of acuity testing, had a complete ophthalmologic examination which included a cycloplegic refraction. Table 1 gives the diagnoses and refractive status of the 37 amblyopic patients. Of the 22 patients with anisometropic amblyopia, predominantly small angle strabismus was also observed in 12 (6 esotropia, 6 exotropia). Although not routinely assessed, eccentric fixation was observed in two patients with anisometropia. Poor foveal reflex was noted on fundus examination of three patients with unilateral high myopia. Amblyopia treatment, prior to testing, included occlusion of the non-amblyopic eye in 16 patients and daily atropine ointment for the non-amblyopic eye of 6 patients. Amblyopia therapy did not affect the acuity comparisons reported in this study.

Results

For children with normal eyes (16 eyes), grating acuities from the small field test were slightly poorer

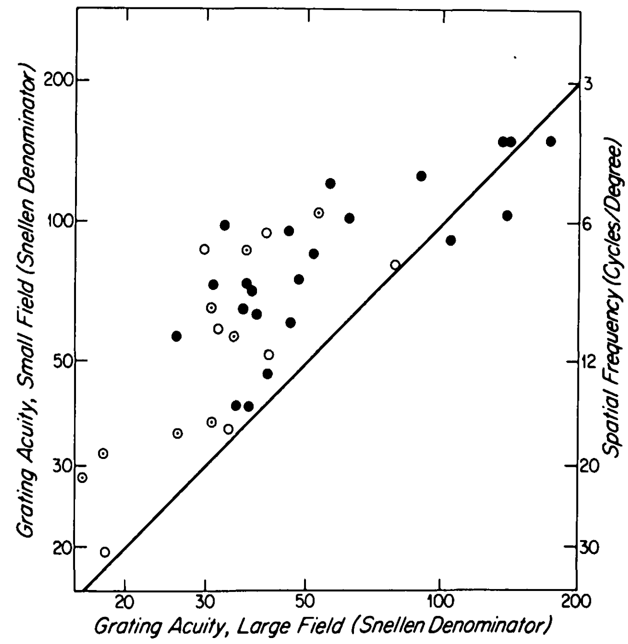

Fig. 1. Small field vs large field grating acuities of 37 amblyopic eyes. Acuity is in Snellen (denominator) and spatial frequency (cycles per degree). Anisometropic amblyopia (22) = filled circles; strabismic amblyopia with no anisometropia (7) = open circles; strabismic amblyopia with anisometropia greater than 1 D spherical equivalent or cylinder (8) = open circles with central dot.

than those obtained by the large field procedure (20/24 vs 20/20); the median difference was 0.2 oct (sd = 0.3). Grating acuities for the adults also differed between large and small field tests, but were better than the children's acuities. Median adult acuity (7 eyes) was 20/16 for the small field test and 20/12 for the large field test; the median difference was 0.3 oct (range 0–1.4 oct). Because of the luminance difference between the small field cards (1.2 log cd/m^2) and the large field apparatus (2.0 log cd/m^2), the adults were also tested with the small field test using the higher luminance; five of seven had identical acuities in the two luminance conditions, one had 0.4 oct better acuity, and one had 0.4 oct worse acuity.

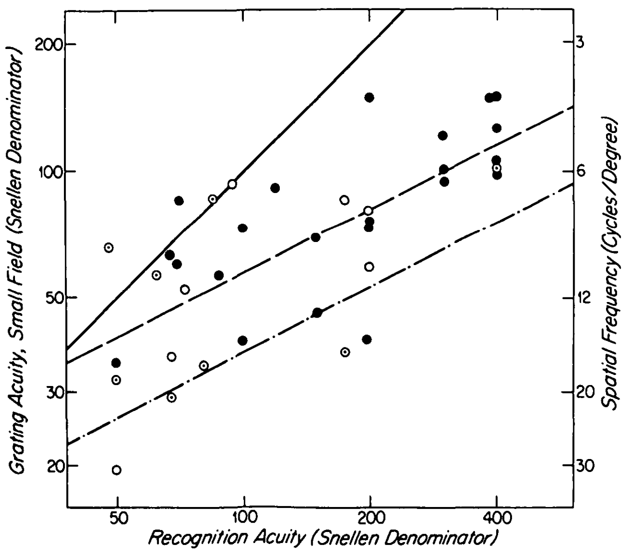

Fig. 2. Small field grating acuities compared to recognition acuities of 37 amblyopic eyes. Axes and symbol conventions are as in Figure 1. The equation for the best fit line by least squares linear regression for the small field grating vs recognition acuities (dashed line) is y = 2.5 + 0.5x (r = 0.7, $P < .01$) and for the large field grating vs recognition acuities (dot-dashed line), y = 1.8 + 0.5x (r = 0.6, $P < .01$).

For the 37 amblyopic patients, small field grating acuities were significantly correlated with large field PL grating acuities (Fig. 1, r = 0.8, $P < .01$), but were generally poorer than large field acuities (mean difference 0.6 oct, sd = 0.5). Small and large field acuities of the 22 anisometropic amblyopes (mean 0.6 oct, sd = 0.5) were as discrepant as those of the 15 strabismic amblyopes (mean 0.7 oct, sd = 0.5; $t < 1.0$). Small and large field grating acuities differed more for the amblyopic eyes than for the non-amblyopic eyes of the 31 patients who did not receive atropine treatment (0.6 vs. 0.3 oct, paired t = 3.1, $P < .005$).

As might be predicted from the above, small field grating acuities were closer to recognition acuities than were large field grating acuities. Nevertheless, small field grating acuities were still better than recognition acuities by a mean of 1.0 oct (sd = 0.7). Mean acuities for the recognition test, small field and large field grating tests were 20/137, 20/67 and 20/44, respectively (ANOVA, F = 7.8, $P < .0001$; all means significantly different, $P = 0.05$).

Figure 2 shows the small field grating acuities in relation to recognition acuities for the 37 patients. Most of the points fall below the solid line of slope 1.0, indicating generally better grating than recognition acuity. The slope of the best fit least-squares linear regression line to the grating vs recognition acuities of less than 1.0 (0.5) indicates an increasing discrepancy between grating and recognition acuities accompanying poorer acuity. In other words, acuity differences were largest for amblyopic subjects with the poorest recognition acuity. Because of the design of the small field stimuli, patients with the poorest acuity also had the most comparable grating and recognition stimulus areas. For the 12 patients with less than a 20% difference in area between small field and recognition stimuli, the median difference between small field grating and recognition acuity was 1.5 oct (range 0–2.3). Notably, despite differences between large and small field grating acuities, the increasing discrepancy with poorer acuity did not differ for the two grating acuity tests, as indicated in Figure 2 by the identical slopes of best fit lines.

The general relation between grating and recognition acuity for both small and large field stimuli is illustrated also by the similar slopes of best fit lines to the interocular acuity differences (IAD's) ($t = 1.6$, $P < .2$) shown in Figure 3. Depth of amblyopia indexed by the grating IADs was smaller than the recognition IADs, as shown by the majority of points below the solid line of slope 1.0. Mean IADs for recognition tests, small field, and large field grating tests were 2.2 oct, 1.3 oct, and 1.0 oct, respectively (ANOVA, $F = 12.3$, $P < .0001$; all means significantly different, $P = 0.05$). Despite the difference between large and small field grating IADs, using the 0.6-oct IAD or two Snellen line difference criterion for amblyopia, the small field grating test detected only 9% more amblyopic patients than the large field PL procedure (24/31, 77% vs 21/31, 68%).

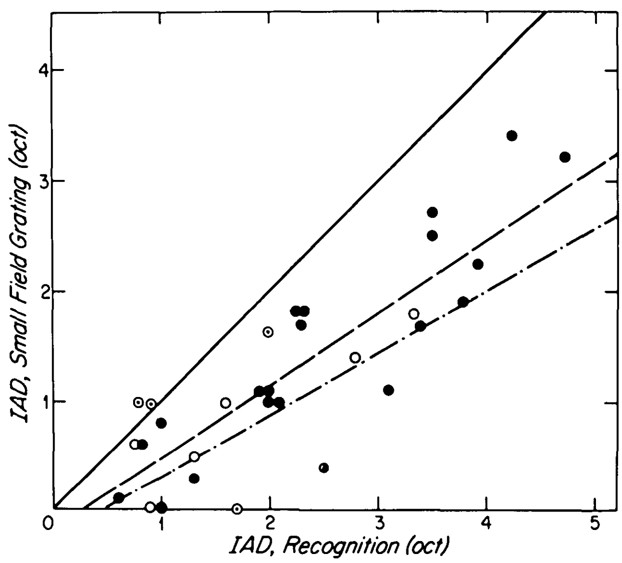

Fig. 3. Interocular acuity differences (IADs) from the small field grating acuity test compared to recognition acuity tests for the 31 amblyopic patients who were not treated with atropine. Symbol conventions are as in Figure 1. The dashed and dotted lines show the best fit functions of small field IADs ($y = -0.19 + 0.66x$, $r = 0.85$, $P < .01$) and large field IAD's ($y = -0.25 + 0.57x$; $r = 0.75$, $P < .01$), respectively, against recognition IADs.

Discussion

Finer grating than recognition acuity, as previously reported for amblyopic subjects,[1-6] was obtained by the majority of the amblyopic children in the present study. Differences between grating and recognition acuities were reduced when gratings were tested in small fields; on the average, however, small field grating acuities remained significantly better than recognition acuities. Had more patients been tested with an array (9/37, 24%) than with single recognition targets, larger differences between grating and recognition acuities might have occurred due to contour interaction.[11,12]

One possible explanation for differences between grating and recognition acuities in the present study is the size difference between grating and recognition stimuli. Contrast sensitivity for gratings is estimated to increase by about 0.7 oct for the average 66% larger area of gratings compared to recognition targets of the present study.[13] Nevertheless, large differences between grating and recognition acuities (median 1.5 oct) persisted for a group of patients with 20% or less difference between stimulus areas.

Grating and recognition acuities may have differed not strictly because of differences in stimulus size, but rather because of differences in the amount of contrast information each stimulus contained. Contrast sensitivity increases with an increase in the number and length of grating cycles, presumably due to spatial probability summation of neural elements.[13-18] The minimum number of grating cycles in the small grating fields was eight. Based upon linear systems analysis, identification of Snellen letters requires up to 2.5 contrast cycles.[19] The increase in contrast sensitivity with an increase in cycles from 2.5–8 is estimated to be 0.3–1.7 oct for a wide range of spatial frequencies.[13-18,20,21] This estimated range of differences, possibly representing a minimum because some recognition targets require less than 2.5 cycles for identification,[19] is within the distribution of differences between small field grating and recognition acuities (mean 1 oct, sd 0.7) found in the present study.

The above explanation does not, however, account for the larger discrepancy between grating and recognition acuities of patients with poor acuities compared to those with less severe acuity deficits. This discrepancy might be due to abnormal spatial probability summation of amblyopic eyes. In two studies of a total of seven amblyopes, contrast sensitivity for low spatial frequencies increased with an increase in cycles at a faster rate for amblyopic eyes than for non-amblyopic eyes.[18,21] Between 2.5–8 cycles, the estimated increase in contrast sensitivity for 0.5–2 cy/deg gratings ranged from 0.5–2.9 oct greater for the amblyopic eyes than for the non-amblyopic eyes.[18,21] In another study of three amblyopic subjects, however, the improvement in contrast sensitivity for low spatial frequencies with increased cycles did not differ for amblyopic and non-amblyopic eyes.[20] Thus, at least for some amblyopic patients with poor acuity, the larger discrepancy between grating and recognition acuity may be due to the greater difference in contrast sensitivity between 2.5 and 8 cycles for the low spatial frequencies that these patients can resolve compared to the smaller discrepancy for patients who can resolve higher spatial frequencies.

Eccentric fixation, although not assessed in the subjects of this study, may also have contributed to differences between grating and recognition acuities. In fact, eccentric fixation may explain the differential spatial probability summation of amblyopic eyes. Five of the seven amblyopes discussed above,[18,21] who had greater than normal probability summation for low spatial frequencies, fixated eccentrically, whereas none of the three patients in the other study,[20] who showed equal probability summation of amblyopic and nonamblyopic eyes, fixated eccentrically. Increases in contrast sensitivity with increasing grating cycles occurs more rapidly for peripheral viewing than for foveal viewing.[17] This means that amblyopic patients with eccentric fixation might benefit to a greater extent from increased stimulus cycles than centrally fixating amblyopic patients. This would be true, however, for all eccentrically fixating patients, including those with relatively good acuity, because the increase in summation in the periphery occurs for all spatial frequencies.[17]

To account for the greater discrepancy between grating and recognition acuities in patients with poor acuity, an additional property of peripheral contrast sensitivity must be invoked. For a constant stimulus size, normal contrast sensitivity falls off with retinal eccentricity more slowly for low spatial frequencies than for high spatial frequencies.[15,17,22] (If however, eccentricity is scaled to spatial frequency[17] or to the cortical magnification of foveal vs peripheral representation,[13] the decrease in contrast sensitivity is the same for all spatial frequencies.)

Together, these phenomena suggest that eccentrically fixating amblyopes with poor acuity should have the greatest discrepancies between grating and recognition acuity, greater than eccentrically fixating amblyopes with relatively good acuity and greater than centrally fixating amblyopes. However, because eccentric fixation was not assessed in the patients of this study, these predictions cannot be directly tested. Nevertheless, the general explanation does not require that amblyopic patients eccentrically fixate; it could simply be that amblyopic vision is similar to normal peripheral vision, as suggested by others.[12,21,27]

Several authors[5,23,24] have suggested contrast threshold measurement is not sufficient to account for deficits in amblyopic spatial vision. They postulate loss of a suprathreshold, phase encoding mechanism to account for various amblyopic deficits, including perceptual distortions[23] and abnormal phase discrimination.[24,25] However, relatively little research has tested explicitly the relation between recognition acuity and other deficits of amblyopic spatial vision. One study showed that recognition acuity was more closely related to vernier acuity than to grating acuity, particularly in strabismic amblyopia.[26] The latter authors[27] proposed an abnormal, spatially localized contrast mechanism as the neural basis for functional amblyopia. The interpretation of the present results, relying upon spatial probability summation of amblyopic eyes and differences in the amount of contrast information within stimuli, could also be formulated as a spatially localized mechanism that is spatial frequency selective.

In disagreement with two previous studies, no differences were found for comparisons of grating and recognition acuities between strabismic and anisometropic amblyopes.[6,26] This lack of agreement between studies might be due to different criteria for categorizing amblyopia and/or differences in patient samples. Alternatively, different distributions of acuities for the strabismic and anisometropic groups could be responsible for this discrepancy. For example, strabismic amblyopes in a previous study had the poorest acuities and the largest differences between grating and recognition acuities[26] (Fig. 1B), whereas, in the present study, anisometropic patients (half of whom are orthophoric) exhibited the poorest acuities and the largest differences (Fig. 2). Nevertheless, important differences between strabismic and anisometropic amblyopes in, for example, vernier acuity,[26] changes in acuity with luminance,[28] and contrast sensitivity of the peripheral retina,[29] indicate different neural bases for these functional amblyopias.

Differences between acuities for the small and large field gratings of the present study may also have been due to spatial probability summation, but only for children with 20/75 or worse acuity. For finer grating acuities, the number of grating cycles was larger than eight and increased with better acuity. In children with normal eyes, the number of small field grating cycles was large and sufficient for complete probability summation.[13,17] Complete or nearly complete probability summation for small grating fields was probable also for amblyopic eyes with 20/70 or better acuity because of their normal probability summation for moderate and high spatial frequencies.[18,20,21]

Therefore, because small differences between small and large field grating acuities were found for normal and amblyopic children with relatively good acuity, it is probable that other factors than spatial probability summation contributed to the differences between grating acuities. For example, stricter criteria for responding, and scoring at a higher percent correct, possible in the small field test, would result in poorer acuity. The lower luminance of the small field gratings could also have resulted in slightly poorer acuity than the PL large field acuity test.[30] Differences between acuities of strabismic and anisometropic amblyopes for grating stimuli varying in luminance, shown in previous studies,[28] would not be expected in the present study because of the high photopic luminance levels used.

In conclusion, at present, the most parsimonious explanation for the relation between grating and recognition acuities obtained in the present study is the differential response of amblyopic eyes to the amount of contrast information within grating and recognition stimuli. The similar relation of both large field and small field grating acuities with recognition acuity suggests that both grating tests measure approximately the same deficit in amblyopic spatial resolution. However, for children testable by both, the eight-alternative test may be preferable because it is more easily administered and the test materials are simpler. To improve the detection of amblyopia using PL procedures, the study of more complex stimuli than homogeneous gratings is warranted.

Key words: amblyopia, children, grating acuity, probability summation, recognition acuity, stimulus size

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