Differences in vernier discrimination for gratings between strabismic and anisometropic amblyopes

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Two gratings composed of lines were displayed one above the other, and the vernier threshold was measured as a function of spatial frequency and vertical separation between gratings for 12 strabismic and/or anisometropic amblyopes. The vernier acuity of the anisometropic amblyopes was similar to that of nonamblyopic eyes when scaled proportionally to their reduced grating acuity. Strabismic amblyopes, on the other hand, have poorer vernier acuity than might be predicted from their grating resolution, even at low spatial frequencies. In addition, the strabismic amblyopes showed "crowding effects" for vernier gratings well within their resolution limit, while anisometropic amblyopes, like normals, showed no such effects. (INVEST OPHTHALMOL VIS SCI 23:398-407, 1982.)

Key words: amblyopia, vernier acuity, psychophysics, grating acuity, Snellen acuity, hyperacuity

Amblyopia is generally considered to be a loss of form vision caused by form deprivation and/or abnormal binocular interaction. In addition to the reduction in visual acuity, elevated contrast thresholds for sinewave gratings over a wide range of spatial frequencies are demonstrated by amblyopes.[1-3] However, grating acuity is less affected by the amblyopic process than is Snellen acuity.[1]

The human eye is exquisitely sensitive to spatial discrimination based on vernier offset. The normal visual system is capable of discriminating offsets that are smaller than a single cone diameter.[4] Since the precision of vernier resolution is better than can be predicted by optical or anatomical considerations, it has been termed "hyperacuity."

Freeman and Bradley[5] measured vernier acuity in a group of amblyopes and reported that the vernier acuity of the amblyopic eye was severely reduced, perhaps to a greater extent than might be predicted from the grating acuity. Since their stimuli were classic single-line vernier targets, it is not clear to what extent this result may have been influenced by eccentric fixation, since vernier resolution falls off rapidly with peripheral viewing (see ref. 6 and Note added in proof).

This article reports on the vernier discrimination of amblyopic observers using an extended vernier grating stimulus to ensure that both the fovea and the eccentric locus are within the stimulus field. The results suggest that (1) the amblyopic process affects vernier grating acuity and Snellen acuity in a similar fashion but affects grating resolution to a much lesser extent, and (2) there appear to be substantial differences between strabismic and anisometropic amblyopes.

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Methods

Vertical vernier gratings were generated on the screen of a computer monitor (Commodore 2001 BN with green phosphor). The gratings consisted of two rows of bright lines on a dark background. The vernier stimulus was an offset between the upper and lower rows. The vertical separation, fundamental spatial frequency of the gratings, and the display field size could be varied, with the constraints that (1) at least 8 cycles of the grating be present in the stimulus field, (2) the field size be at least 3 times the distance between the fovea and the eccentric fixation locus to ensure that the grating be presented to both the fovea and the eccentric locus, and (3) the vernier offset be no larger than a quarter of the duty cycle. The smallest offset that the computer could generate was 0.38 mm. Therefore, to reach vernier threshold the nonamblyopic eyes were tested at a viewing distance of 10 to 11 m from the display. The amblyopic eyes were tested at closer distances, proportional to the observer's grating acuity and in line with the constraints described above. To rule out edge cues, bars with random offsets were placed between the test stimulus field and the edge of the display. A schematic of the stimulus is shown as an inset in Fig. 1, A.

The psychophysical paradigm was a self-paced method of constant stimuli, with multiple responses. Trials were presented in blocks. A given block of trials contained four different stimuli; the lower row of gratings was presented with one of two possible offsets to the left or one of two offsets to the right of the top row. The order of the stimuli was randomized, and the presentation time was approximately 1 sec. A fixation target was provided between trials to aid in fixation and accommodation. The observer's task was to signal whether the lower grating was offset to the left or right of the upper grating and to rate his/her certainty. After each trial, feedback as to the direction and magnitude of the offset was provided. The magnitude of the offsets, the spatial frequency, and the vertical gap between gratings was varied between blocks of trials. Prior to data collection, each observer was provided with several hundred practice trials, and 10 to 20 practice trials were provided at the start of each new block to minimize practice effects.[7] The computer presented the stimuli, tallied the responses, and gave feedback. To obtain a criterion-free measure of the discriminability of the stimuli, a maximum likelihood estimate of the d′ was made,[8] and interpolation to a d′ of 1 was used as a measure of the vernier threshold. Each condition was repeated several times and the results presented represent the means. Standard errors were approximately 10% to 20% of the mean.

Snellen acuity was determined with the E charts designed by Davidson and Eskridge.[9] These charts maintain a constant interletter separation and therefore a constant (high degree of) contour interaction. The acuity values correspond to full-chart Snellen acuity; however, acuity measures with the E charts are more reliable.[9] For each observer, a psychometric function relating the percentage of correct responses to the minimum angle of resolution of the Es was determined. The acuity threshold was taken as the 75% correct level.

Observers. Twelve adults with unilateral amblyopia due to strabismus (four subjects), anisometropia (five subjects), or both (three subjects) participated in these experiments. All had clear media, normal fundi, and appropriate correction for refractive error during the experiment. Several of the observers had previously participated in psychophysical or electrophysiological experiments. The visual characteristics of each of the observers are provided in Table I.

Results

Table I shows the psychometric Snellen acuity, the grating cutoff spatial frequency in cycles/degree,* and the best vernier acuity, expressed both in minutes of arc and as a percentage of the grating resolution limit measured under the same conditions. The vernier data shown in Table I represent the mean vernier thresholds obtained with low spatial frequency gratings (i.e., at least 3 octaves below the resolution limit) and with no vertical separation between the two rows. For the nonamblyopic eyes, the mean vernier threshold under these conditions was 0.19 ± 0.01 min arc or 15.8% ± 0.6% of the resolution limit. This result is similar to that obtained for practiced normal observers under the same conditions. For the amblyopic eyes, the vernier thresholds varied from 0.38 to over 20 min arc.

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*The duty cycle of the gratings for the cutoff spatial frequency measurements was about 12% (i.e., the line width was one eighth of the interline distance), providing a contrast of the fundamental spatial frequency equal to 195%. This high contrast accounts for the good visibility of high spatial frequencies in this study.

Table I. Visual characteristics of the 12 observers

Observer	*Age/sex*	*Eye*	*Refractive status*	*Fixation of amblyopic eye*
Anisometropic				
B.J.	23/F	OD	Plano	Unsteady, ½° to 1° nasal + superior
		OS	+4.00-1.25 × 110	
D.S.	22/F	OD	+4.50-1.00 × 90	Unsteady, central
		OS	+1.00	
M.M.	22/F	OD	+0.50	Unsteady, central
		OS	+2.75-1.25 × 075	
T.G.	58/M	OD	−7.00-2.25 × 180	Unsteady, 1° temporal
		OS	−4.50-1.50 × 165	
V.S.	55/M	OD	+8.00	Unsteady, ½° superior
		OS	+4.00-0.75 × 085	
Strab/aniso				
D.B.	24/M	OD	−7.00-0.50 × 25	Unsteady, ½° nasal
		OS	−5.50-1.75 × 30	
J.V.	25/M	OD	+0.75-0.25 × 070	Unsteady, 1° nasal + superior
		OS	+4.50-0.50 × 023	
L.H.	23/F	OD	+2.00-1.25 × 175	Unsteady, 2° nasal + inferior
		OS	−1.25-0.50 × 160	
Strabismic				
R.G.	28/M	OD	−4.50-1.25 × 090	½° Temporal
		OS	−5.00-1.00 × 090	
C.W.	28/F	OD	Plano	Unsteady, 1° temporal
		OS	Plano-0.25 × 070	
A.G.	29/F	OD	+0.50-0.25 × 015	Unsteady, within ½° to 1°
		OS	+1.00	
J.M.	32/M	OD	+0.75-0.50 × 105	Unsteady, 1° to 2° nasal + inferior
		OS	+0.75-2.25 × 083	

Strab/aniso = subjects with both strabismus and anisometropia; OD = right eye; OS = left eye.

If the amblyopic process affected vernier acuity and grating acuity in the same manner, then it might be expected that vernier acuity would be a constant percentage of the grating resolution limit. Thus, for example, if grating acuity were reduced by a factor of two in the amblyopic eye and vernier acuity were also reduced by a factor of two, then vernier acuity, when expressed as a percentage of the grating resolution limit, would be similar in amblyopic and nonamblyopic eyes.

In the five anisometropic amblyopes without strabismus, and in subject D. B. with both strabismus and anisometropia, vernier acuity appears to be scaled in roughly the same manner as their grating resolution. The other six amblyopes, all with strabismus, show vernier acuity that is considerably worse than would be predicted from their grating resolution. In fact, two of the strabismic amblyopes (A. G. and J. M.) show vernier thresholds two to three times greater than their grating resolution thresholds. This may be seen graphically in Fig. 1, *A*, in which grating acuity is plotted against vernier acuity. The data of the anisometropic amblyopes tend to show vernier acuity which is 2.5 to about 4 times better than grating acuity. At low spatial frequencies, the data of D. B. is similar to those of the anisometropic amblyopes. The results for the other six amblyopes with strabismus tend to fall close to the 1 : 1 line or to the right of it; that is, vernier acuity is actually poorer than grating acuity.

Thus it appears that the amblyopic process may affect vernier acuity to a greater extent than grating resolution, particularly in cases of deep amblyopia resulting from strabismus. Gstalder and Green[1] originally suggested that grating acuity may be better than Snellen acuity in patients with amblyopia, and this finding has been confirmed by other investigators.[10-12] Fig. 1, *B*, shows the relationship between grating acuity and Snellen acuity for the 12 amblyopic observers tested. Points falling below the diagonal line (1 : 1

Binocularity	*Snellen acuity*	*Grating resolution (cy/deg)*	*Vernier threshold (min arc)*	*Vernier threshold (% of resolution)*
No strabismus	20/15	41	0.24 ± 0.04	18
	20/30	20	0.52 ± 0.10	20
No strabismus	20/35	24	0.38 ± 0.10	17
	20/15	41	0.16 ± 0.03	14
No strabismus	20/15	43	0.24 ± 0.04	19
	20/37	16	0.60 ± 0.14	18
18$^{\Delta}$ Exophoria	20/50	16	0.72 ± 0.14	21
	20/20	41	0.24 ± 0.04	17
No strabismus	20/132	8	1.06 ± 0.24	16
	20/15	40	0.18 ± 0.04	13
6$^{\Delta}$ Constant OS ET W hyper	20/15	41	0.24 ± 0.06	18
	20/30	20	0.52 ± 0.10	20
8$^{\Delta}$ Constant OS ET	20/20	43	0.18 ± 0.04	14
	20/80	19	1.50 ± 0.30	55
16-20$^{\Delta}$ Constant OD ET w3$^{\Delta}$ hyper	20/104	16	1.19 ± 0.23	37
	20/15	41	0.16 ± 0.02	14
6$^{\Delta}$ Constant OS XT	20/15	43	0.18 ± 0.04	16
	20/46	29	0.72 ± 0.16	38
12-15$^{\Delta}$ Constant OD XT w 10$^{\Delta}$ hyper	20/153	14	2.12 ± 0.22	57
	20/15	46	0.20 ± 0.04	18
35-40$^{\Delta}$ Constant OS XT w23$^{\Delta}$ hypo	20/18	45	0.18 ± 0.04	15
	20/400	20	9.24 ± 0.89	354
12$^{\Delta}$ Constant OS ET w 5$^{\Delta}$ hypo	20/15	46	0.16 ± 0.02	14
	20/483	6	20.76 ± 2.1	238

ratio) show better grating acuity than Snellen acuity. While the data of nonamblyopic eyes, of anisometropic amblyopes, and of subject D. B. (strabismic and anisometropic) fall near (but slightly below) the 1:1 line, the results for the other six amblyopes (with strabismus) show much greater departures from the 1:1 line. In the cases of strabismic amblyopes A. G. and J. M. with Snellen acuity values of 20/400 (20′) and 20/483 (24′), respectively, the grating acuity greatly underestimates the losses in both Snellen and vernier resolution.

Fig. 1, *C*, shows the relationship between Snellen acuity and vernier acuity for the nonamblyopic eyes and amblyopic eyes of each of the observers. Most of the results approximate the 4:1 relationship, suggesting that the amblyolic process may affect vernier and Snellen acuity in a similar fashion. However, for the two deep strabismic amblyopes A. G. and J. M., the fourfold superiority of vernier over Snellen acuity is diminished. For these two observers the vernier acuity approaches the Snellen acuity, perhaps suggesting that the Snellen acuity represents a limit for the loss of vernier acuity. The results shown in Fig. 1, *C*, are surprising; although extensive research has been carried out on letter recognition and on vernier acuity, we know of no previous research that has closely linked the two. The high degree of correlation between the two acuities as shown by amblyopes makes one wonder whether a robust correlation between vernier acuity and letter recognition exists (particularly under conditions of strong contour interaction or "crowding") in normal observers. It would be interesting to compare the two acuities under different levels of blurring, luminance, crowding, and peripheral viewing.

The results presented thus far raise the question of whether vernier and Snellen acuities are abnormally low in strabismic compared with anisometropic amblyopia, or whether the grating acuity is abnormally low in anisometropic amblyopes? A comparison of the population distributions of each acuity measure for our sample shows that strabismic and anisometropic amblyopes have identical grating acuity distributions but that the strabismic amblyopes have a broader vernier and Snellen distribution due to the preponderance of poorer vernier and Snellen acuities. Therefore it seems reasonable to conclude that it is the strabismic amblyopes in our sample who have the added anomaly of spatial vision.

Effects of spatial frequency. The spatial frequency of the fundamental component of the vernier grating is the reciprocal of the horizontal spacing of the lines. This will simply be referred to as the spatial frequency of the grating throughout this article. The vernier results shown thus far, obtained at low spatial frequencies and with no vertical separation between the upper and lower rows of gratings, represent the subject's best vernier resolution. In nonamblyopic eyes vernier acuity is independent of spatial frequency over a wide range of spatial frequencies. The vernier acuity (expressed as a percentage of the grating resolution limit) of the nonamblyopic eyes and amblyopic eyes of seven amblyopes are plotted as a function of the fundamental spatial frequency of the vernier gratings in Fig. 2. The results show that vernier acuity is more or less independent of spatial frequency until the spatial frequency of the vernier grating is within about an octave of the resolution limit (the mean cutoff spatial frequency is shown by the arrow marked NAE, and the range is given by the horizontal error bar). Similar results were obtained for the anisometropic observers (Fig. 2, *A*). For each of the anisometropic amblyopes, vernier acuity remained fairly constant until the vernier grating approached the resolution limit (shown by the arrows for each observer). The results for the strabismic amblyopes (Fig. 2, *B*) showed rather different effects. For these observers, increasing the spatial frequency of the vernier grating resulted in marked increases in the vernier threshold, even at very low spatial frequencies. This "crowding phenomenon"[13] for vernier acuity occurred at spatial frequencies well below the resolution limit in all of the strabismic amblyopes, even those with mild acuity and grating losses (e.g., the data of subject R. G. shown by the squares) but was not evident in the results of the anisometropic amblyopes without strabismus. This is shown more clearly in Fig. 3. Here the abscissa has been scaled to take into account the observer's resolution limit (in octaves). For nonamblyopic eyes the mean vernier acuity (Fig. 3, dotted line) is independent of spatial frequency until the spatial frequency of the gratings is within about 1 octave of the resolution limit. Similar results were obtained for the amblyopic eyes of anisometropic amblyopes (Fig. 3, open symbols). In all the anisometropic amblyopes vernier acuity remained constant up to 1 octave below the resolution limit. In contrast, the amblyopes with strabismus (Fig. 3, solid symbols) show marked "crowding" at spatial frequencies well below their resolution limit. Thus, for each of the amblyopes with strabismus (including D. B.), the vernier threshold approximately doubled between 3 and 2 octaves below the resolution limit, and they were unable to see any amount of offset for gratings almost 2 octaves below the resolution limit. For each of the strabismic amblyopes, including the two most severe amblyopes (A. G. and J. M., not shown in Fig. 3), vernier thresholds could not be measured for higher spatial frequencies due to their extremely poor vernier discrimination and the constraints imposed by the repetitive stimulus.

Effects of vertical separation. Introducing a vertical separation between the upper and lower rows of vernier gratings results in an elevation of vernier thresholds for nonamblyopic eyes and for the amblyopic eyes of both strabismic and anisometropic amblyopes. Fig. 4 shows vernier acuity (expressed as a percentage of grating resolution) as a function of vertical separation for both the nonamblyopic and amblyopic eyes for three observers at several different spatial frequencies. For both eyes of each observer the vernier threshold appears to approximately double for each 2.5-fold change in vertical separation, regardless of the level of vernier acuity when the lines are abutting.

Effects of retinal locus. The reduction in vernier acuity of amblyopic eyes appears to be greatest in the fovea, with the amblyopic and nonamblyopic eyes becoming more similar in peripheral view. The ordinate in Fig. 5, *A*, shows the vernier thresholds for observer D. S. (anisometropic amblyopia with central fixation). Circular masks of various diameters were placed over the center of the field so that 10 cycles of the grating, outside of the mask, were visible. A fixation target was presented in the center of the mask. The abscissa in Fig. 5, *A*, shows the diameter of the central area mask. With no central mask, the vernier thresholds for the amblyopic eye of this observer were about twice that of the nonamblyopic eye, whereas with the central 3° masked, thresholds for the two eyes were similar. These results are also consistent with the notion that the amblyopic fovea is similar in many respects to normal periphery.[14, 15]

Effects of feedback. Pugh[16] and more recently Hess et al.[10] reported that some strabismic amblyopes perceived distortions when viewing suprathreshold stimuli. Bedell and Flom[17] have reported that strabismic amblyopes make abnormally large constant errors in partitioning experiments when viewing with their amblyopic eyes. If this constant error varies either in time or across visual space as suggested by Bedell and Flom,[17] then it could make tasks such as vernier judgments difficult, particularly under high spatial frequency conditions.

In the present experiments the effects of constant errors in perception were mini-

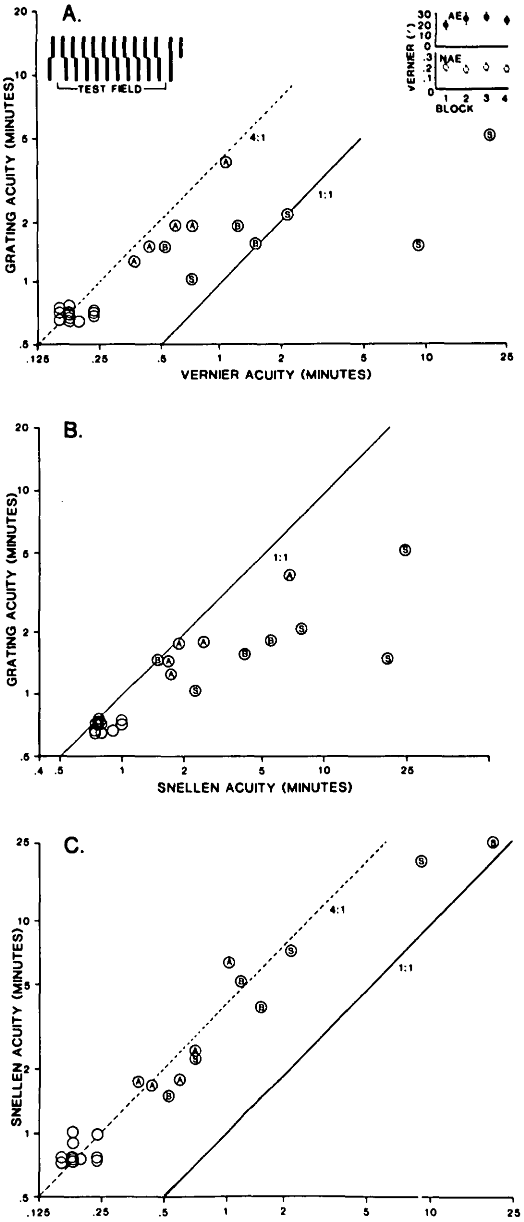

Fig. 1. For legend see left column.

Fig. 1. A, Grating acuity vs. vernier acuity (min) for each eye of the 12 observers. The coordinates are log-log. *Open circles,* Nonamblyopic eyes; *solid line,* 1:1 line; *dashed line,* 4:1 ratio between grating acuity and vernier acuity (i.e., vernier thresholds 4 times lower than grating thresholds). Data for eyes with amblyopia due to anisometropia *(A),* strabismus *(S),* and both strabismus and anisometropia *(B)* are shown. The vernier acuity is for low spatial frequency gratings (at least 3 octaves below the resolution limit). **Left inset,** Schematic representation of the stimulus. Note that the stimulus actually consisted of bright lines on a dark background. **Right inset,** Mean vernier acuity for each eye of observer J. M. on four blocks of trials to illustrate absence of practice effects. Error bars are ±1 S.E. **B,** Grating acuity vs. Snellen acuity (min) for each eye of the 12 observers. Details are as in **A. C,** Snellen acuity vs. vernier acuity (min) for each eye of the 12 observers. Details are as in **A.**

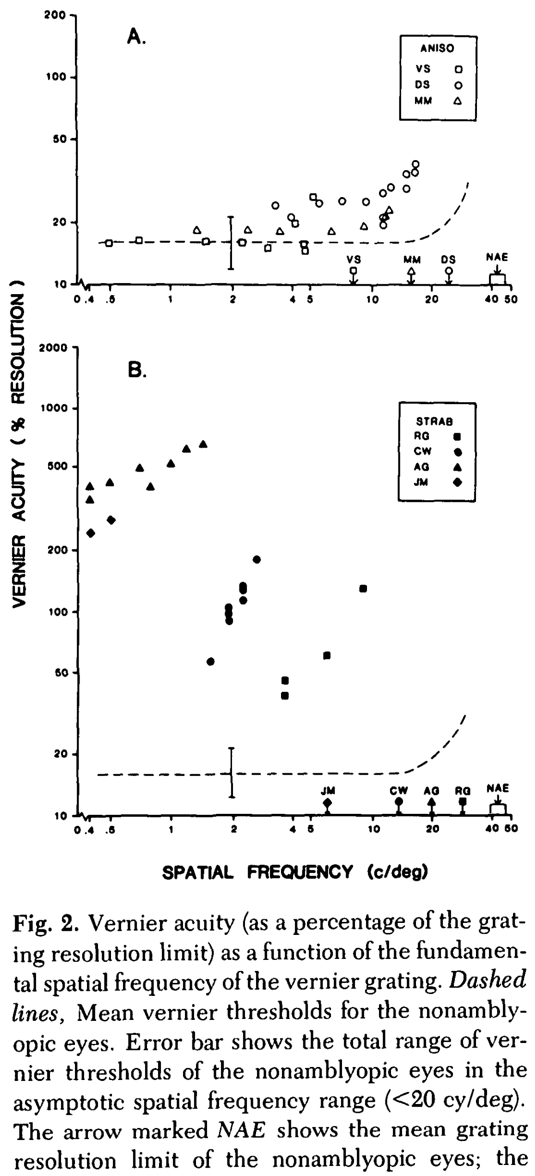

Fig. 2. Vernier acuity (as a percentage of the grating resolution limit) as a function of the fundamental spatial frequency of the vernier grating. *Dashed lines,* Mean vernier thresholds for the nonamblyopic eyes. Error bar shows the total range of vernier thresholds of the nonamblyopic eyes in the asymptotic spatial frequency range (<20 cy/deg). The arrow marked *NAE* shows the mean grating resolution limit of the nonamblyopic eyes; the horizontal error bar is the range. The arrows with symbols show the grating resolution limit for the amblyopic eye of each observer. **A,** Data for the amblyopic eyes of three anisometropic amblyopes. **B,** Data for the amblyopic eyes of four strabismic amblyopes.

mized, since the feedback allowed the observers to make corrections for these errors. The results shown in Fig. 5, *B* and *C*, are from blocks of trials in which feedback was not provided (all other experimental details were unchanged). The proportion of "right" responses and "left" responses are plotted for four different offsets (i.e., two offsets to the right and two to the left). Each point is based on 40 trials. The data in Fig. 5, *B*, are for the amblyopic eye of anisometropic amblyope D. S. The solid arrow shows the crossover, which may be regarded as a locus of subjective alignment; the open arrow shows this locus when feedback was provided. For this observer, with and without feedback, the crossover occurred within 0.05 min of physical alignment. The results in Fig. 5, *C*, are for strabismic and anisometropic observer J. V. For this observer, the locus of subjective alignment was displaced by slightly more than 1 min arc from the locus of physical alignment. Interestingly, the slopes (thresholds) were essentially identical with and without feedback; however, with feedback, the constant error is negligible (shown by the open arrow).

Discussion

The results of the present experiments suggest that (1) the amblyopic process affects vernier discrimination and Snellen acuity in a different manner than simple grating acuity, (2) Snellen and vernier acuities may be closely related, and (3) there appear to be substantial differences between the responses of strabismic and anisometropic amblyopes. For the anisometropic amblyopes, the optimal vernier acuity obtained at low spatial frequencies appeared to be roughly scaled to the resolution limit, while all of the amblyopes (except D. B.) with strabismus (Fig. 1, S or B data points) showed vernier discriminaion that was poorer than that predicted from their grating resolution. Only D. B., a minimal amblyope (20/30) who had previously undergone successful treatment, showed vernier acuity that was scaled to his resolution limit. The low spatial frequency results, although highly suggestive, are not completely unambiguous, since some of the strabismic observers may show improvement in vernier acuity at still lower spatial frequencies. However, all the strabismic amblyopes (including D. B.) demonstrated "crowding effects" for vernier gratings that were well within their resolution limit (i.e., two to three octaves or more

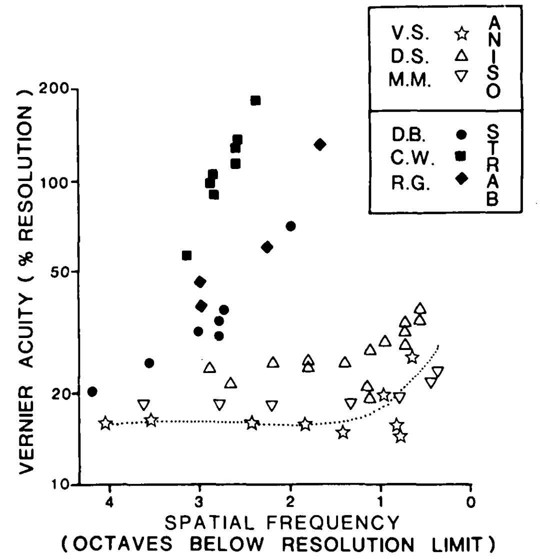

Fig. 3. Vernier acuity as a function of the fundamental spatial frequency of the grating. Both the abscissa and the ordinate have been scaled to take into account each observer's grating resolution. The vernier acuity (ordinate) is represented as a percentage of the grating resolution. The spatial frequency of the gratings (abscissa) is scaled in octaves (1 octave = 0.3 log unit) below the resolution limit. For nonamblyopic eyes, vernier acuity is about 16% of the resolution limit for spatial frequencies an octave or more below the resolution limit *(dotted line)*. Anisometropic amblyopes *(aniso)* show similar results when vernier acuity is scaled to their grating resolution. Strabismic amblyopes *(strab)* show marked "crowding."

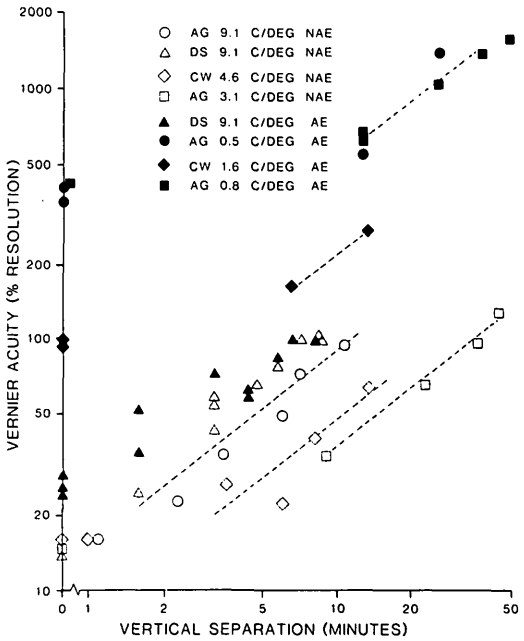

Fig. 4. Vernier acuity (as a percentage of grating resolution) as a function of the vertical separation between the two rows of gratings (log-log coordinates). *NAE,* Nonamblyopic eyes; *AE,* amblyopic eyes. The data coincident with the ordinate are with no vertical separation. *Dashed lines,* 2.5:2 relationship between vertical separation and vernier thresholds.

below their resolution limit), whereas the anisometropic amblyopes without strabismus did not demonstrate such effects (Figs. 2 and 3). This "crowding effect" for vernier gratings may be similar to the crowding effect for letters, which is characteristic of amblyopes.[13] One possible interpretation is that the amblyopic eye is simply unpracticed at making discriminations. This seems to be an unlikely explanation for the present results, since each observer was given extensive practice with each eye prior to data acquisition, and repetitions of the same stimuli gave consistent results. This may be seen in the inset in Fig. 1, *A,* which shows the repeatability of the vernier thresholds for observer J. M. on four consecutive blocks of trials. Furthermore, the results cannot be explained on the basis of criterion differences (response bias), since the signal detection paradigm with feedback minimizes criterion effects.

Freeman and Bradley[5] measured vernier acuity in amblyopes by means of classic vernier stimuli. They reported that the deficits in vernier acuity correlated loosely with those of contrast sensitivity but that vernier function was relatively more impaired. The present results are in substantial agreement with their data and show further that the abnormalities in the vernier acuity of amblyopes cannot simply be ascribed to eccentric fixation, since the vernier gratings always included the fovea in the stimulus field. It is also unlikely that the present results can be explained on the basis of unsteady fixation, since good vernier acuity does not require a steady target.[18] To test this point, the display was rotated by 90° for several of the ambly-

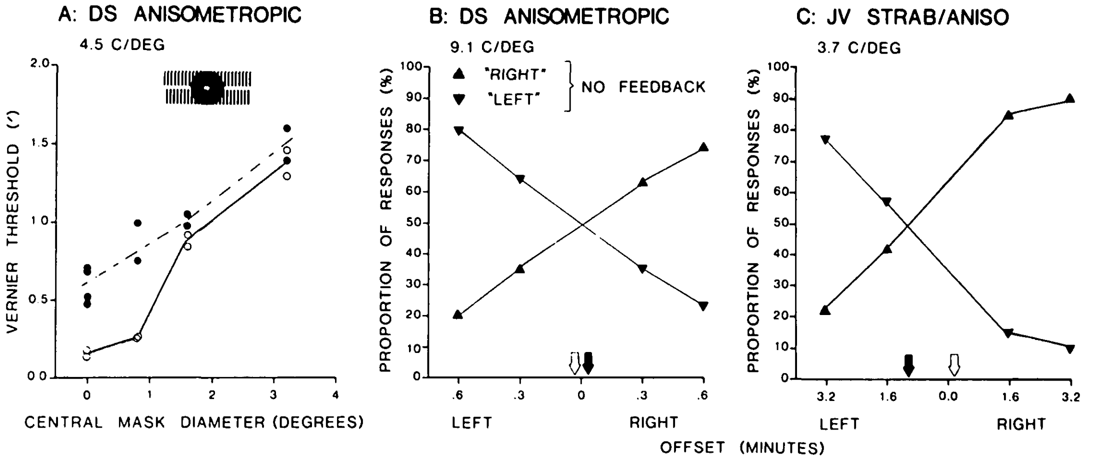

Fig. 5. **A**, Vernier thresholds (min) as a function of the diameter of a central mask (shown schematically) for observer D. S. *Open circles*, Nonamblyopic eye; *filled circles* amblyopic eye. **B**, Proportion of "right" responses and "left" responses of observer D. S. for a block of trials with four offsets in which no feedback was provided. *Solid arrow*, Locus of subjective alignment under this condition, *open arrow*, locus of subjective alignment under the same stimulus conditions, with feedback. **C**, As in **B** for anisometropic and strabismic amblyope J. V.

opic observers who demonstrated horizontal fixation nystagmus. This strategy will reduce the effects of smearing of the retinal image due to horizontal eye movements. The results obtained with horizontal gratings were substantially the same as those obtained with vertical gratings.

Hess et al.[10] and Bedell and Flom[17] suggested that spatial distortions would have a severe effect on the identification of complex targets, e.g., optotypes, while influencing the visibility of repetitive gratings to a lesser extent. Two of the amblyopic observers in the present study (J. V. and J. M.) reported perceptual distortions when viewing with the amblyopic eye. These distortions may most closely be described as monocular diplopia. Interestingly, many of the amblyopes, including severe amblyope A. G., reported that the vernier grating stimuli appeared similar to the two eyes, except that the offset was difficult to discern with the amblyopic eye. In addition, many strabismic amblyopes appear to demonstrate constant errors in perception.[17] If these constant errors vary either in time or space, then it is quite likely that both vernier acuity and Snellen acuity would be severely affected, while grating acuity would be affected to a much lesser extent. Whereas the constant errors of strabismic amblyopes can be modified by feedback, their abnormal spatial sense as reflected in their poor discrimination of vernier gratings was not modified by feedback.

In summary, the present results suggest that in amblyopia associated with anisometropia, the loss of vernier acuity and Snellen acuity is roughly scaled to the reduction in grating resolution; however, in more marked levels of amblyopia associated with strabismus the losses in vernier and Snellen acuity are much greater. These results, in conjunction with the results of Hess et al.[19] provide support for the notion that there exist differences in the effects of strabismus and anisometropia on the developing nervous system. In addition, these results suggest that studies of humans with abnormal vision may be useful in understanding the relative contributions of the various components of visual acuity.

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Note added in proof

The rapid fall of vernier acuity in the periphery has recently been confirmed (Westheimer G: Vision Res **22**:157, 1982).

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