The influence of the stimulus width on the contrast sensitivity function in amblyopia

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The contrast sensitivity function of both eyes of subjects with functional amblyopia has been measured. A clinically significant difference was found between the amblyopic and the normal eye. It appears that the functionally amblyopic eye takes more information from the peripheral parts of the stimulus than does the normal eye. The sensitivity of the normal eye increases linearly with increasing width of the stimulus to show a knee at a certain number of grating lines, whereas the sensitivity remains constant. The sensitivity of the amblyopic eye initially rises much faster than that of the normal eye with increasing stimulus width. In the amblyopic eye, there is no definite linear relationship between width of stimulus and the contrast sensitivity and no definite knee in the curve at which maximum sensitivity is reached.

Key words: amblyopia, sinusoidal spatial frequency grating, contrast sensitivity function

In recent contrast sensitivity function (CSF) studies in amblyopia,1-4 it was found that in some cases the sensitivity of the amblyopic eye for low spatial frequencies was greater than that of the fellow normal eye. We found in our series, measured with vertical sinusoidal spatial gratings with a field of 8.5° wide by 5° high, that amblyopes with a visual acuity greater than 0.1 showed a marked increase in sensitivity in the low-frequency area as compared to the normal fellow eye. This was not found in subjects with a visual acuity of less than 0.1. Although it is recognized that the diminished visual acuity in amblyopia may be caused by a defective contrast mechanism, the size of the object can also be of importance. To test this supposition, we measured the CSF with the stimulus width as an extra parameter. The effect of the variation of stimulus width or number of presented spatial cycles on the CSF of the normal eye is known.5-9 From these studies van der Wildt et al.5 have suggested that the contrast sensitivity as a function of the stimulus width within the range of spatial frequency 0.5 to 4 cycles per degree (c/d) is at least partially caused by nonhomogeneity of the retina and/or the neural visual system. From this article5 and further hitherto unpublished material we concluded that the high spatial frequencies are only detected in the fovea. As the frequency is lowered, the use of an increasing part of the central retina is necessary for the optimal detection of the presented grating. This seems to hold true until the whole 10° to 12° of the central retina is used (at a luminance of 10 cd/m² as used by the authors), at which point the area used for detection does not seem to increase. Since an amblyopic eye has an impaired detection for fine structures in comparison to its fellow eye, the influence of the stimulus width on the contrast sensitivity function in amblyopia is of interest.
normal eye it is presumed that this is caused by an altered retinal or neurological organization of the foveal area of the affected eye. But since it was found that the sensitivity of the amblyopic eye was greater than that of the normal eye for coarse patterns in some cases, we can presume that the periphery of the macular area in amblyopia will also differ in its structure in comparison to a normal eye.

To examine this possibility, we have measured the CSF of a number of amblyopic subjects in experiments where not only the frequency, but also the width, of the presented stimulus or number of grating cycles was varied against the modulation depth.

Methods

The stimulus used was a vertical sinusoidal grating presented on the screen of a Tektronix picture monitor Model 622 (with phosphor WA D 6500). The average luminance of the stimulus was 10 cd/m². The viewing distance was varied depending on the type of measurement made. When a complete modulation transfer function was measured from 0.1 to 25.6 c/d, the width of the stimulus was varied by placing black masks before the screen, and two viewing distances were used. The monitor was placed 50 cm from the eye of the subject for frequencies lower than 0.4 c/d and at 200 cm for the higher frequencies, to compensate for limitations in the monitor system at high frequencies. The visual field of the image presented on the monitor could be viewed up to 33.5° wide at 50 cm and up to 8.5° at 200 cm. The height was 5° in all cases.

In those cases where the width of the stimulus was varied at constant frequency, the screen was placed at 100 cm from the subject. The field size of the image could be varied up to 17.5° wide at a constant height of 5°, by using black masks. A small fixation light was projected at the center of the stimulus with both systems. The subject viewed the screen directly. The surround of the presented stimulus was black, and the room in which measurements were taken was darkened. The modulation depth or contrast of our stimulus is defined as follows:

$$M = \frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}} + L_{\text{min}}} \times 100\%$$

where \(L_{\text{max}}\) = luminance of brightest part of the grating and \(L_{\text{min}}\) = luminance of darkest part of the grating.

Clinical data of the four amblyopic subjects in this study are presented in the Appendix.

Two procedures were used to determine the contrast threshold. Subjects A. W. and B. S. were measured with the forced-choice method, in which the subject's task was to discriminate the grating from a homogeneous field of the same size and average luminance. The percentage of correct responses from 20 random presentations of each stimulus was determined in terms of the modulation depth. A score of 75% correct, corresponding to the detection of half the presented grating stimuli, was defined as the threshold. Each stimulus was presented for 1 sec, with a 1 sec dark interval. Despite the drawbacks of this method as far as time expenditure was concerned, we used it to make our first results comparable to earlier experiments of our department with normal subjects and also with our earlier CSF measurements on these subjects.

The CSFs of the other subjects were obtained by using a modified Von Bekésy method. In this system, all functions (except those of the subject) were controlled by a microprocessor system developed at our department. (A technical description of this method by Keemink et al. will be published in Biology & Medical Engineering and Computing.) The subject is able to diminish the contrast of the grating by depressing a switch. As soon as the contrast is subthreshold, the subject releases the switch, which causes the contrast to increase. When the grating is just visible, the subject depresses the switch again. This process is repeated 10 times, and the modulation depth is varied around the subject's threshold. The higher and lower contrast-reversal values are averaged, and this value is taken as the threshold. To avoid adaptation effects, the first four reversal values are not used. The average value is thus determined from eight reversal points. The microprocessor then plots the average results against the frequency or number of grating lines, depending on the type of measurement made on an X-Y plotter. When the CSF over the whole frequency range is recorded from 0.1 to 25.6 c/d, the measuring procedure starts at the lowest frequency; when the contrast sensitivity for this frequency has been plotted, the following frequency, double the first, is automatically presented on the screen, and so on until the whole visual spatial frequency spectrum has been transversed.
Fig. 1. Modulation transfer functions of the amblyopic eye (left) and the fellow normal eye (right), Subject A. W. The width of the stimulus was varied from 0.25° to 8° visual angle.

The measurement of the contrast sensitivity of a given frequency, with variation of the stimulus width, still proved very costly in time with the Von Békésy method because this has not been fully automatized yet, and we have only been able to measure the CSF for one frequency with two of our further subjects (F. F. and L. d. W.).

These results are given in Fig. 3 along with the results for comparable frequencies of our first two subjects.

Discussion

The CSF of the amblyopic eye shows a greater increase in sensitivity with increasing width of the presented stimulus than does the CSF of its fellow normal eye.

Although at small widths of the stimulus the sensitivity of the amblyopic eye is greatly reduced in comparison to the normal fellow eye, it makes up for this deficit in the middle-and low-frequency ranges as the width of the presented stimulus increases and becomes comparable to the normal CSF findings.1-4 This can even go so far in some cases that the amblyopic eye shows a heightened sensitivity in the low-frequency range at greater stimulus widths. Although in

possible to determine the CSF for both eyes in about 25 min and to record a family of CSF curves at four different stimulus widths in about 2 hr.

Results

The results of our first two amblyopic subjects, A. W. and B. S., were obtained with the forced-choice method described previously. This proved to be a very exhausting method, taking about 2 hr per CSF per width per eye.

The results of A. W. are presented in Fig. 1. From this figure it is clear that the CSF of the amblyopic eye decreased far faster with the reduction of the width of the presented stimulus than that of the normal eye. This finding proved consistent when we repeated these measurements with other amblyopic subjects (where the measurements were made with the modified Von Békésy method, taking only 10 to 12 min per CSF per width per eye). The results obtained in this way proved fully comparable to those obtained with the forced-choice method. The influence of the width of the presented stimulus becomes clear if the contrast sensitivity is plotted against the width per frequency as shown in Fig. 2 for Subject A. W.
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Fig. 2. Variation of threshold sensitivity vs. the width of the presented stimulus for different preset frequencies, Subject A. W.

the case of Subjects B. S. and F. F. (with a visual acuity of 1.5/60 and 0.5/60 in the amblyopic eye, respectively) no heightened sensitivity in the low-frequency region was found for the maximum width measured, the CSF curves of the amblyopic eye also showed a much more marked increase in sensitivity as the width was increased than the normal fellow eye. The above-mentioned increase in sensitivity with stimulus width was also found in our other amblyopic subjects.

An elevated sensitivity in the low-frequency region was only found in those subjects with a visual acuity greater than 0.1. This was also the case at greater widths of presentation. Since the measurements by Hess and Howell,2 Gstalder and Green,1 and Sjöstrand3 were made with a presentation size of 3.7°, 4°, and 1.4°, respectively, their findings of an elevated sensitivity in the low-frequency region were not so marked as ours,4 in which we measured the CSF in our subjects with a screen width of 8.5°. Had we obtained our data with screens of their sizes, we should also not have found, as we did in many cases, an elevated threshold sensitivity in the low-frequency region for our amblyopic subjects with a visual acuity greater than 0.1. Our findings most likely differ from those of Hess and Howell41 for large stimulus sizes due to the darkened surround and the mesopic adaptation level used in our measurements. It is easier to interpret the conduct of the eye with varying stimulus widths when the variation of contrast threshold with stimulus width at constant frequency is plotted as in Figs. 2 and 3. Here it can be seen that the sensitivity of the normal eye increases more or less in proportion to stimulus width to a certain point and then remains constant. The amblyopic eye clearly does not react in this way. In the amblyopic eye, the increase in sensitivity shows a much faster initial rise and ultimately reaches its maximum at far greater stimulus widths. Here also (Fig. 3) the marked heightened sensitivity of the amblyopic eye can be seen in those subjects with a visual acuity greater than 0.1, whereas those with a lower vision in the amblyopic eye do not show this phenomenon.

It is interesting to note that in the normal eye of Subject A. W., the size of the field where maximum sensitivity is reached varies as the reciprocal of the frequency (Fig. 4). The field width at which the knee occurs cor-
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Fig. 3. Variation of threshold sensitivity vs. the width of the presented stimulus for one frequency (2 c/d for Subjects B. S. and A. W.; and 1.6 c/d for Subjects F. F. and L. d. W.). The drawn line is the sensitivity curve for the amblyopic eye; the dashed line indicates the fellow normal eye.

Fig. 4. Relationship between the width of the stimulus at which no further increase in sensitivity occurs and the spatial frequency for the normal eye of Subject A. W. Data taken from Fig. 3.

respects to 5 grating lines. This holds for frequencies above 0.5 c/d and corresponds to a maximal field of 10° which corresponds to the anatomical macular area. We also found this correlation in the earlier measurements of van der Wildt et al.5

In the amblyopic eye this linear relationship is not evident. There is no sharp knee in the threshold sensitivity curve, but the incremental increase in sensitivity diminishes slowly with increasing width. However, in the low-frequency and lower middle-frequency range, this can lead to a greater sensitivity for the amblyopic eye at greater widths, and it indicates that the amblyopic eye is able to make use of the information of a larger central retinal area to attain its maximal sensitivity.

Conclusion

We conclude that there is a definite difference between the behavior of the CSF curves of normal and amblyopic eyes when the width of the presented stimulus is varied. This difference must be caused by a difference in the homogeneity of the retinal organization and related visual pathways. In normal subjects, it is presumed that the varying field size at which maximum contrast sensitivity is reached, depending on the frequency, is caused by nonhomogeneity of the retinal organization and/or related visual neurological structures.5

The impaired detection of fine structures
by the amblyopic eye compared to its normal fellow eye is presumed to be caused by an altered retinal or neurological structure of the foveal area. But since it was found that the rate of increase of the contrast sensitivity in the amblyopic eye with increasing width of the presented field also differs from that of the normal eye, often presenting an elevated sensitivity with larger fields at low spatial frequencies, we can presume that the whole of the macular area, including the periphery thereof, will also differ in its structure from the normal eye. We hope that this difference can be used for the possible clinical diagnosis of amblyopia, especially in those cases with a visual acuity lower than 0.1 where no heightened sensitivity in the low-spatial-frequency range has been found to date. However, this could possibly be caused by the fact that we have not yet presented these subjects a large enough field in the lower frequency range (i.e., below 0.5 c/d).

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REFERENCES

Appendix

Table I A. Clinical data of the four amblyopic subjects who took part in this study

<table>
<thead>
<tr>
<th>Subject</th>
<th>Landolt C-ring acuity</th>
<th>Type of amblyopia</th>
<th>Refractive correction</th>
<th>Fixation of amblyopic eye</th>
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<tr>
<td></td>
<td>OD</td>
<td>OS</td>
<td>OD</td>
<td>OS</td>
</tr>
<tr>
<td>A. W.</td>
<td>0.4</td>
<td>1.25</td>
<td>Squint</td>
<td>S - = c - 1 150°</td>
</tr>
<tr>
<td>B. S.</td>
<td>2.0</td>
<td>1.5/60</td>
<td>Anisometropia</td>
<td>S + 0.5 = c - 0.25 180°</td>
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<td>F. F.</td>
<td>0.5/60</td>
<td>2.0</td>
<td>Squint</td>
<td>S + 0.75</td>
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<tr>
<td>L. d. W.</td>
<td>0.5</td>
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