Specific Reading Disability: Differences in Contrast Sensitivity as a Function of Spatial Frequency

Abstract. *Contrast thresholds for sine-wave gratings of spatial frequencies of 2, 4, 12, and 16 cycles per degree were determined for normal and disabled readers at a range of stimulus durations. Normal readers demonstrated monotonically decreasing sensitivity with increasing spatial frequency at exposure durations between 40 and 100 milliseconds. At exposure durations of 150 to 1000 milliseconds, they showed peak sensitivity at 4 cycles per degree. In comparison, disabled readers showed monotonically decreasing sensitivity with increasing spatial frequency at all stimulus durations. The difference in sensitivity pattern across spatial frequencies was greatest at stimulus durations approximately equal to fixation durations during reading.*

A long and controversial research history concerns possible visual factors in specific reading disability (*1*). While numerous reports (*2*) have shown no differences between good and poor readers in spatial perception, more recent studies have indicated that the two groups differ in terms of their spatio-temporal processing (*3*). This conflict may relate to methods of assessing visual capacity. Specifically, although clinical patients with problems in pattern perception and reading have normal visual acuity, they have more subtle visual deficits that become evident when vision is assessed by determining the contrast sensitivity function (*4*). We have now demonstrated that normal and disabled readers differ in the pattern of sensitivity across spatial frequencies and that this difference depends on stimulus duration. At short stimulus durations, both groups showed a monotonic decrease in sensitivity with increased spatial frequency. With longer stimulus durations, especially those which approximate reading fixation durations, normal readers were most sensitive at 4 cycles per degree, whereas disabled readers continued to show a monotonic decrease in sensitivity. Comparison of the two groups in terms of critical duration as a function of spatial frequency reveals no significant differences. This result indicates that the visual persistence differences mediated by spatial frequency that have been reported between good and poor readers (*5*) are likely to be cortical and not retinal in origin.

A stimulus property fundamental to the processing of spatial information is spatial frequency measured in terms of the number of cycles of a sine-wave grating per degree of visual angle. Recent physiological (*6*) and psychophysical (*7*) research has indicated that different spatial stimuli may be processed in separate channels rather than in a single channel. The contrast sensitivity function, a measure of visual performance across all spatial channels, has useful clinical applications (*8*) in situations in which normal acuity tasks have proved inadequate. Individual channels process only a limited range of spatial frequencies and differ in temporal properties measured by reaction time (*9*), critical duration (*10*), and visual persistence (*11*). There seem to be two components to visual persistence (*12*), only the second of which, influenced by grating orientation and contrast, is presumably cortical (*13*). The first component has properties similar to temporal integration and may result from such integration. Stimuli shorter than the critical duration may consequently measure both components, whereas longer stimuli measure only the second component.

The slope of the function relating visual persistence to spatial frequency is significantly flatter in disabled than in normal readers (*5*). Because persistence was measured with stimuli of short duration, there was no indication of the persistence component on which normal and disabled readers differed. We therefore compared normal and disabled readers in terms of the contrast sensitivity function at a range of stimulus durations In addition to revealing subtle visual deficits concealed by standard optical assessments, this method also provides a measure of temporal integration (retinal persistence) at each spatial frequency.

Contrast thresholds for reading-disabled and control subjects were obtained for sinusoidal gratings of 2, 4, 12, and 16 cycles per degree at stimulus exposure durations of 40, 60, 80, 100, 150, 200, 300, 500, and 1000 msec. Two groups of ten 14-year-old boys matched in intelligence (*14*) and socioeconomic status were tested. The disabled readers had average intelligence and an average reading age lag of 5 years on the Neale Analysis of Reading Ability (*15*), showed no gross behavioral problems, and suffered from no organic disorders. Both groups had 6/6 Snellen acuity or better.

A 2° (diameter) sine-wave grating display (space-averaged luminance of 2.2 cd/m^2) was presented on a cathode-ray tube (B.W.D. model 539D, ^{31}P phosphor). Either a target (grating) or catch (blank) trial was initiated when the subject pressed a button. Subjects were required to report the presence or absence of the grating on each trial.

Contrast thresholds were determined according to the blockwise tracking procedure (*16*). Each block consisted of 12 trials—six target trials and six catch trials. In succeeding blocks, contrast was either increased or decreased from the starting contrast, previously determined by preliminary testing to be close to threshold. Testing continued until subjects achieved 75 percent accuracy in any one block or bracketed 75 percent accuracy between any two successive blocks. The presentation order for spatial frequency and duration was counterbalanced. Each subject was tested in at least two sessions. Viewing was binocular throughout.

The control data are consistent with data previously reported for adults (*10*), showing a monotonic decrease in sensitivity with increase in spatial frequency (from 2 to 16 cycles per degree) at short durations (40 to 100 msec) (Fig. 1). With longer durations, control subjects began to show peak sensitivity at 4 cycles per degree.

Only at the longest duration used (1000 msec) did disabled readers begin to show a sensitivity peak at 4 cycles per degree. Analysis of variance revealed that a significant ($P < .05$) or near significant ($P < .10$) groups-by-frequency interaction for the quadratic trend (*17*) occurred for all stimulus durations from 150 to 500 msec. Thus, the sensitivity pattern differences (Fig. 1) are significant. The pattern in the two groups did not differ with the 1000-msec stimulus duration. These analyses consequently show that, for stimulus durations similar to fixation durations in reading, normal and disabled readers have considerable differences in the shapes of their contrast sensitivity functions.

The relative miss and false-alarm rates for the two groups were compared by Mann-Whitney U tests, which revealed no differences between the groups. It is unlikely, then, that these results are produced by differences in criterion setting between the two groups.

Critical durations for each subject (*18*) under each condition were obtained by standard procedures (*13*). Because of the correlation between the means and variances for each condition, a logarithmic transformation was applied to the raw data before analysis. There were no significant differences between the two groups [$F(1, 18) = 2.5$, $P > .05$]. The significant effect of spatial frequency

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[$F(3, 54) = 7.0$, $P < .01$] showed that critical duration increased with spatial frequency in 14-year-olds as well as in adults (*10*). There was not a significant interaction between reading ability and spatial frequency [$F(3, 54) = 1.4$, $P >$ .05].

In terms of the two-component theory of visual persistence (*13*), it can be concluded that the frequency-mediated differences in visual persistence between normal and disabled readers at ages 8 (*5*) and 14 (*19*) years do not result from differences in the retinal component. Presumably the difference arises at the cortical level. There are two further sources of evidence for this conclusion. Contrast, which influences cortical but not retinal persistence (*13*), influences persistence differently in disabled and normal readers (*19*). In addition, the pattern of persistence in normal and disabled readers across spatial frequencies differs most when stimuli of long duration (*19*) are used to measure the cortical component. How differences in visual persistence mediated by spatial frequency may influence reading has been discussed elsewhere (*11, 19*).

The different patterns of contrast sensitivity between the two groups may be compared with those reported by Bodis-Wollner (*4*). He reported that adult clinical patients with altered sensitivity to limited spatial frequency ranges experienced difficulty in pattern perception and reading. Recovery of normal sensitivit, after treatment was accompanied by the return of normal pattern recognition and reading ability. The selective losses in spatial frequency sensitivity in some of his subjects resembles that reported here for disabled readers at intermediate stimulus durations.

Our analysis indicates that disabled readers should experience a general visual deficit on many integration tasks. Difficulties in reading should be only one manifestation of the problem. Because the differences in sensitivity patterns between the two groups are greatest with stimulus durations approximately equal to reading fixation durations, the problems may be maximized in reading. That disabled readers do have a more general spatio-temporal problem is shown in a recent study (*20*) requiring subjects to identify pictorial and verbal material moved behind a stationary slit (*21*). Disabled readers had more difficulty than control subjects with both sorts of stimuli, a result indicating a general deficit in spatio-temporal integration. It is possible that the differences reported here underlie such difficulties.

The contrast sensitivity differences between the groups reported here differentiated the individuals in each group almost without exception (*22*). Consequently, this measure may provide an easy means of screening young children for potential reading problems before they begin to read. Furthermore, the results merit consideration in terms of constant claims that normal and disabled readers do not differ visually (*2*) and, consequently, that remediation approaches should concentrate on "intact visual abilities" (*23*).

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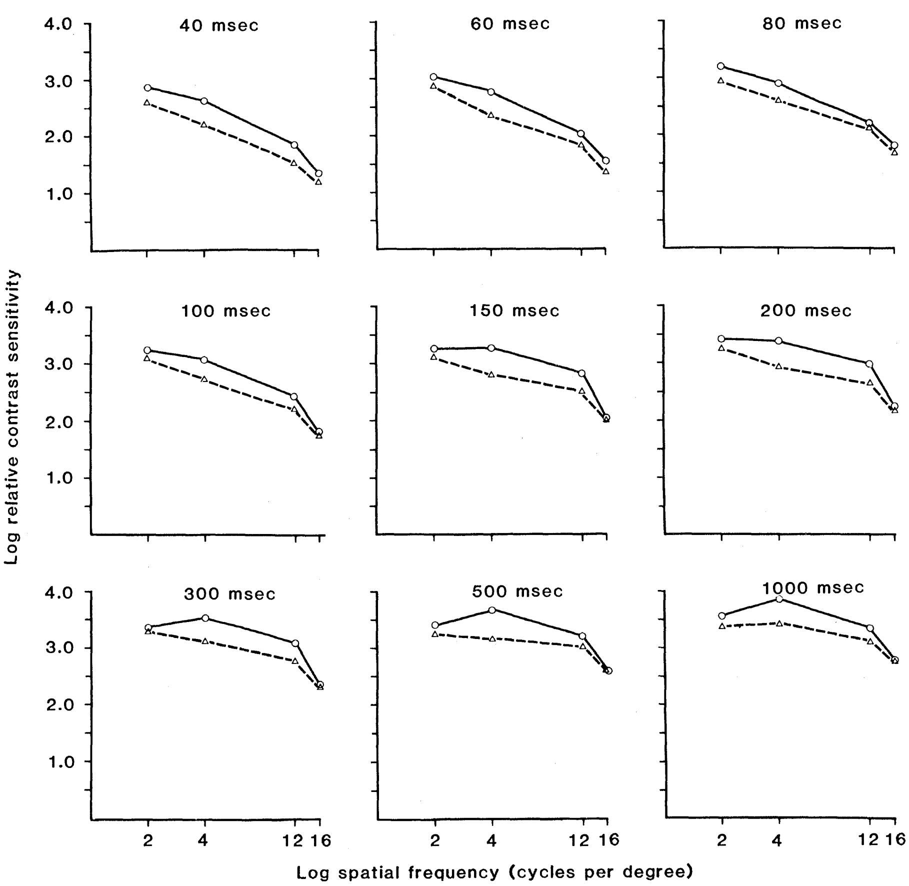

Fig. 1. Contrast sensitivity functions as a function of stimulus duration for the reading-disabled (△) and the control (○) groups.

References and Notes

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