7.5: Reading: Letters, Words, and Their Spatial-Frequency Content

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Abstract

Previous research is consistent with the view that pattern recognition in reading is based on the outputs of independent narrow-band spatial-frequency channels. We describe the results of four experiments that suggest that pattern recognition in reading proceeds on a letter-by-letter basis relying on broad-band spatial-frequency inputs.

1 Background and Objective

In a series of previous studies in this laboratory, we have used psychophysical methods to examine the role of vision in reading performance. We have two major goals: to understand the role of sensory mechanisms in normal reading, and to understand how visual disorders impair reading. As part of this work, we have measured the effects on reading speed of important text variables including character size, contrast, luminance and color. In the present paper, we address two questions concerning sensory coding in reading: Is pattern recognition in reading a letter-by-letter process or does it apply to word shape as a whole? Does pattern analysis in reading occur in independent narrow bands of spatial frequency (i.e. independent spatial-frequency channels?)

Legge et al. (1985) measured reading speed as a function of the bandwidth of lowpass spatial-frequency filtered text (i.e. blur.) They found that high reading speeds could be sustained when the bandwidth extended at least one octave in spatial frequency above the fundamental frequency of the letters, independent of angular character size. (The "fundamental spatial frequency" of a letter is one cycle/letter.) In another study, Legge et al. (1987) showed that character-size effects on reading speed for low-contrast texts could be explained in terms of visual contrast sensitivity in the same one-octave-wide bands. Together, these results are consistent with the view that pattern recognition in reading is based on a letter-by-letter analysis, using information contained in a narrow band of spatial frequencies extending upward from the fundamental frequency. Possibly, this information is encoded in the independent spatial- frequency channels identified in sinewave grating detection studies (Campbell & Robson, 1968). We refer to this possibility as the "channel model" for reading.

We conducted four experiments to explore the "channel model" for reading.

2 Experimental Findings

In all the experiments, reading speed was measured for texts displayed on a computer-driven Conrac TV monitor. Subjects were required to read the texts aloud as rapidly as possible.

2.1 Experiment 1. Highpass Filtering

It has often been proposed that pattern analysis in reading is based on word shape rather than individual letters. The lowpass filtering experiment described above does not exclude the possibility that spatial frequencies below the fundamental frequency of letters contribute to reading. It is possible that such low frequencies convey useful word-shape information that is distinct from letter information.

We compared reading speeds for unfiltered texts and texts that were highpass filtered to remove spatial-frequency content below one cycle/letter.

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There was no significant difference in reading speed for the filtered and unfiltered texts. This result implies that coarse word-shape information, distinct from letter information, does not play an important role in reading.

2.2 Experiment 2. Mixed Polarity

Figural grouping in vision can be controlled by contrast polarity. For example, the white squares on a chess board may group perceptually to give the impression of diagonals. If words are analyzed as unitary patterns, then interleaving light and dark letters should be quite disruptive to reading.

We compared reading speeds for three types of texts: all light letters on a gray background, all dark letters on a gray background, and randomly mixed light and dark letters on a gray background. Reading speed was no slower in the mixed-polarity text than for either of the pure texts. The fact that reading is "blind" to contrast polarity argues against pattern analysis based on word shape.

2.3 Experiment 3. "Ransom Notes"

The last two experiments used bandpass filtering. In each, two bands were used. The "low band" extended from 1 to 2.5 cycles/character and the "high band" from 4.5 to 12 cycles/character. The filters were 8th-order Butterworth filters. Three viewing distances were used. Table 1 shows the corresponding retinal spatial frequencies measured in cycles/degree.

	Spatial Frequency Range	
Distance	Low-band	High-band
1 meter	0.7–1.7	3.2–8.1
2.2 meters	1.5–3.7	7.1–17.7
3.22 meters	2.2–5.4	10.4–25.9

Table 1: Retinal Spatial Frequency Ranges of the Two Bands at the Distances Used (cycles/degree)

In the "ransom note" experiment, we compared reading speeds for three types of texts: all low-band characters (Figure 1), all high-band characters (Figure 2), and "ransom notes" in which low- and high-band characters were randomly alternated (Figure 3).

Reading speeds for the pure cases (all low-band or all high-band letters) varied with the retinal spatial

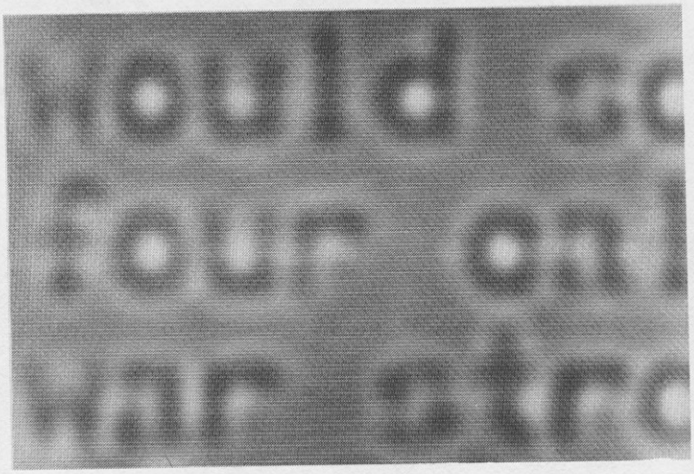

Figure 1: Fragment of a Low-band Stimulus

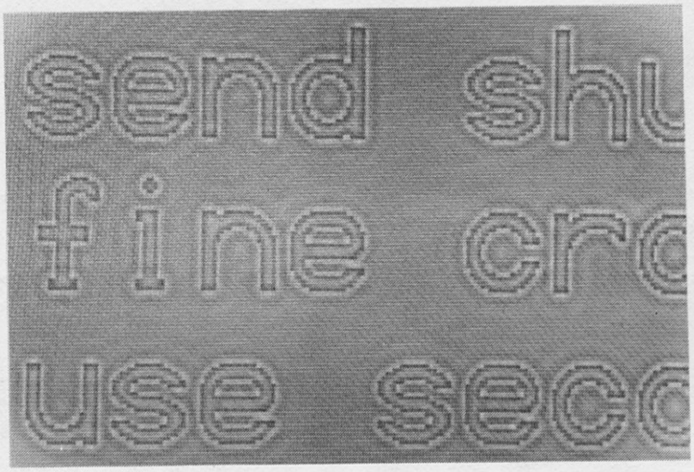

Figure 2: Fragment of a High-band Stimulus

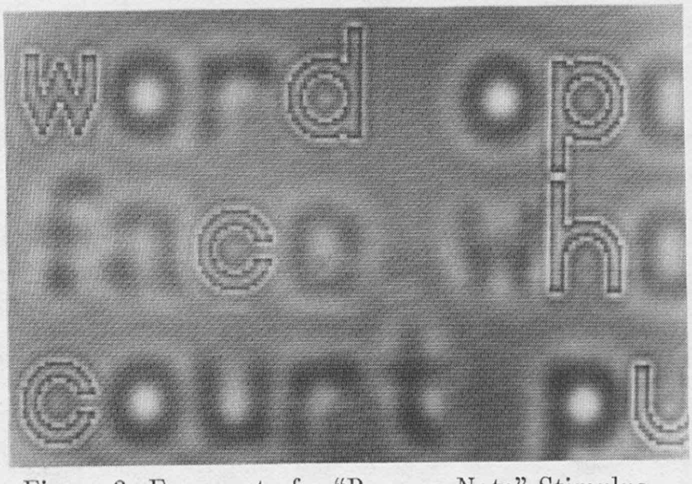

Figure 3: Fragment of a "Ransom Note" Stimulus

frequency of the band and were qualitatively consistent with a channel model in which the channel sensitivities vary with spatial frequency.

More revealing, however, were the "ransom notes". When bands were used for which pure low-band and pure high-band reading speeds were roughly matched, there was very little decrement in reading speeds for the corresponding ransom notes. This means that subjects can read texts in which letters within words are filtered into widely separated bands of spatial frequency. This result implies a letter-by-letter analysis. Furthermore, it implies that high-speed reading can be supported by sensory signals from widely separated spatial frequencies, inconsistent with a narrow-band channel model.

2.4 Experiment 4. Text Masking

In the final experiment, we directly tested the channel model for reading. We created displays in which pure high-band texts were superimposed on pure low-band texts. If subjects can use narrow-band channels to read, it should be possible to read either the low- or high-band text without interference from the other in a stimulus containing both (Figure 4). Such a result would be analogous to the previous finding that sinewave gratings of one spatial frequency can be detected with little or no effect from masker gratings if the maskers are sufficiently remote in spatial frequency.

Inconsistent with the channel model for reading, we found substantial masking effects. There was no viewing condition in which texts in the high and low bands could both be read at speeds close to unmasked levels. There were asymmetries in the masking effects that varied with the retinal spatial frequencies of the two bands, but strong masking effects were always present.

This result suggests that letter recognition in reading is not confined to stimulus information in narrow bands of spatial frequency.

3 Impact

From a theoretical perspective, the results argue for letter-by-letter pattern recognition in reading and against a simple narrow-band spatial-frequency channel model. It is possible that the sensory substrate for reading is an early (perhaps cortical) sensory representation based on narrow bands of spatial frequency. However, some further transformation into letter features may use information across a wide range of spatial frequencies prior to letter recognition.

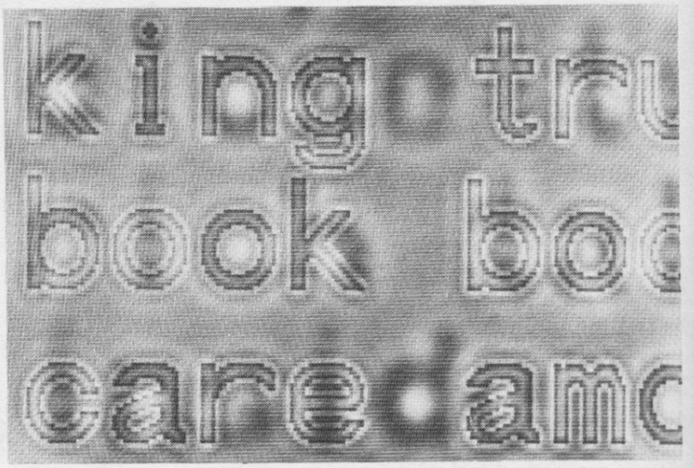

Figure 4: Fragment of a Text Masking Stimulus

There are two consequences for the design of text displays. First, text can be conveyed by narrow bands of spatial frequency, only about an octave in width. It is possible to design low-resolution displays that are quite legible. Second, although narrow bands of spatial frequency can support rapid reading, pattern information in remote bands can mask reading. For example, superimposing letters on fine textures or coarse luminance undulations may result in reduced reading performance.

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