Crowding Affects Reading in Peripheral Vision

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SUMMARY

It has been shown in various studies that identification of a letter is harder when it is surrounded, or "flanked," by other letters than when the letter is presented alone. This "crowding" effect occurs only in peripheral vision and not in the fovea. The purpose of this paper is to explore the crowding phenomenon as a cause of why people read poorly in the periphery. The results show that under conditions where crowding should occur, observers perform badly on word identification.

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INTRODUCTION

Normal reading consists of two main activities, one motor and one sensory. A person's eyes make a series of saccades, rapid ballistic movements, across the text (Rayner and Bertera, 1979). Between the saccades, when the eyes are relatively stationary, the reader acquires the necessary visual information for detecting and recognizing the word (Higgins et al., 1996). It's a task that many of us take for granted, but there are those who cannot.

(1a) (1b) (1c)

Figure 1: Figure 1a shows the visual span of a normally-sighted reader. Figure 1b is a popular but misleading idea about the visual span of a person with central-field loss. Figure 1c is the more accurate picture of the visual span of such a person. (Legge, 1999)

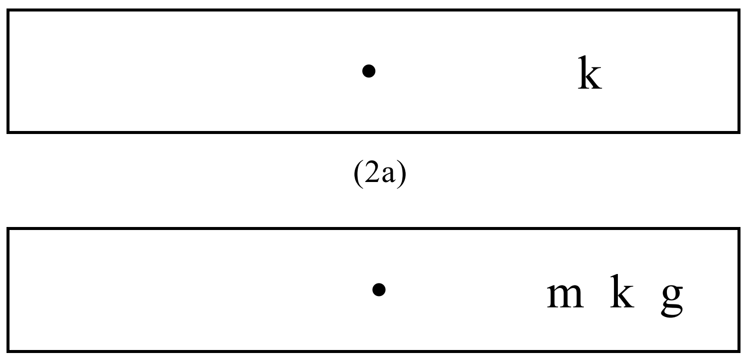
Individuals with normal vision often have the misleading impression that they can see a whole page of text at one glance. But they can really only recognize a few letters at a time, as shown in Fig. 1a. People with central-field loss, such as patients with macular degeneration, cannot use their fovea to read and are forced to use their peripheral vision. Fig. 1b shows a common misconception of reading with central-field loss. A more accurate depiction is shown in Fig. 1c (Legge, 1999).

It has been found in various studies that targets presented at the point of fixation are likely to be detected more quickly and accurately than targets presented in the periphery (Wolfe et al., 1998). Periphery is measured in degrees of eccentricity with the fovea being 0 degrees. The further out you go, the greater the eccentricity. Many have tried to figure out why peripheral reading is so much worse and others have tried to neutralize the effect of eccentricity.

A cortical magnification factor is often used to try to correct for the effect of eccentricity. Letter size is scaled so that the farther one goes out into the periphery, the larger the print size becomes (Chung et al., 1998). This method yielded various results with some experiments suggesting it helped (Latham and Whitaker, 1996) and others saying it had no effect (Chung et al., 1998).

One theory of poor peripheral reading suggests that saccades are not as proficient in the periphery as in the fovea. Thus, if saccadic eye movements are eliminated, reading speed in the periphery might reach that of the fovea. Rapid serial visual presentation (RSVP) presents text sequentially, one word at a time at the same location in the visual field (Rubin and Turano, 1994), thereby abolishing eye movements. Under this hypothesis, RSVP reading in the periphery should be as fast as saccadic reading in the fovea. However, RSVP reading rates were found to be slower in the periphery than the fovea (Higgins et al., 1996).

This paper aims to investigate the idea that "crowding" might be the cause of poor peripheral reading. Crowding, also termed "lateral masking," is a phenomenon in which a target letter is surrounded, or flanked, by other letters. When presented in the periphery, identification of the target letter is more difficult in the presence of flanks. The crowding effect is more pronounced in the periphery than in the fovea (Leat et al., 1999).



(2b)

Figure 2: Fixate on the dot and try to identify the letter shown at the periphery. It's harder to do in Figure 2b because crowding occurs. The flanking letters, *m* and *g*, seem to merge with the target letter, *k*, making it harder to identify.

Leat et al. (1999) describe crowding as contour interaction, a type of neural interaction or lateral spatial masking caused by the proximity of contours near the target. When a target letter is embedded in a string of letters, the flanks seem to merge with the target, making the word look like one large unreal letter. This merging of the letters makes it difficult to identify the central letter.

Bouma (1972) showed that the flanks of an object presented in the periphery must be spaced less than half the eccentricity away to produce a crowding effect. In other words, if a word is presented at 10 degrees eccentricity, the letters within the word should be less than 5 degrees apart in order to see a crowding effect.

The following experiments were set up to test out Bouma's conditions and to see the crowding effect occur.

In one block, subjects identify single vowel letters. In another block, they identify three-letter words. The words were created by flanking a vowel with two constant letters. This is done for both foveal viewing, where crowding is not expected, and peripheral viewing (5 degrees eccentricity), where crowding should occur. Following Bouma's criterion, we expect crowding at 5 degrees if the letter spacing is 2.5 degrees or less. It is speculated that crowding will make words harder to identify than letters.

The experiment will also be performed in another alphabet, Hindi, to test the idea that crowding is a property of the stimulus independent of the observer's language.

Hindi was chosen as the foreign alphabet because its complexity is equal to that of Bookman, the font used for the English text. Complexity is defined as inside-and-outside perimeter, squared, divided by "ink" area (Pelli et al., 1999). Simply put, a Chinese character is more complex than an English letter.

METHODS

Two observers participated in this study- myself and a fluent Hindi speaker, who has practiced Hindi since elementary school.

The experiments were written in the computer language MATLAB, with the Psychology Toolbox extensions (Brainard, 1997; Pelli 1997).

The signals used in the first part of the experiment were the English vowels "a, e, i, o, u" in Bookman font with a height of one degree. The subject sat 100 cm away from the computer screen, which displayed a black dot directly in the center to serve as the point of fixation. When she clicked her mouse, the computer flashed a letter for 200 milliseconds on a background of visual noise (See Fig. 3). Then a menu of the five possible signals was displayed and the subject used her mouse to click on the letter she thought had been flashed. A correct answer was rewarded with a beep. The computer randomly chose the signal and its contrast. A high contrast letter is very bright and easily identified; a low contrast letter can barely be detected, much less identified.

(3a) (3b)

Figure 3: The signals presented without noise, as pictured in Figure 3a, and in noise, Figure 3b.

Forty trials were done where the signal was presented without noise, followed by 40 trials in noise. A 40-trial run provided a threshold estimate, the letter contrast necessary for the observer to get 82% of the trials correct. Thresholds were reported for trials done in a noise background.

In the next part of the experiment, the signals were changed to "b_g" words, in which the computer randomly picked a vowel to fill in the central target letter. The subjects still had five possibilities to choose from (i.e. bag, beg, big, bog, bug).

The subjects then performed the same task with Hindi "vowels," which were merely five common Hindi letters chosen by the fluent Hindi observer.

Figure 4: The five Hindi "vowels" used in the experiment.

Then, just as in the Bookman experiments, five Hindi words were used, with the target letter being one of the previous vowels and possessing the same flanks. The Hindi words used are real Hindi words and not nonsense words.

Figure 5: A Hindi "vowel" is flanked to create a word.

All four tasks were done with the signals presented in the fovea and at an eccentricity of 5 degrees. A total of eight tasks was performed in the experiment by each observer.

RESULTS

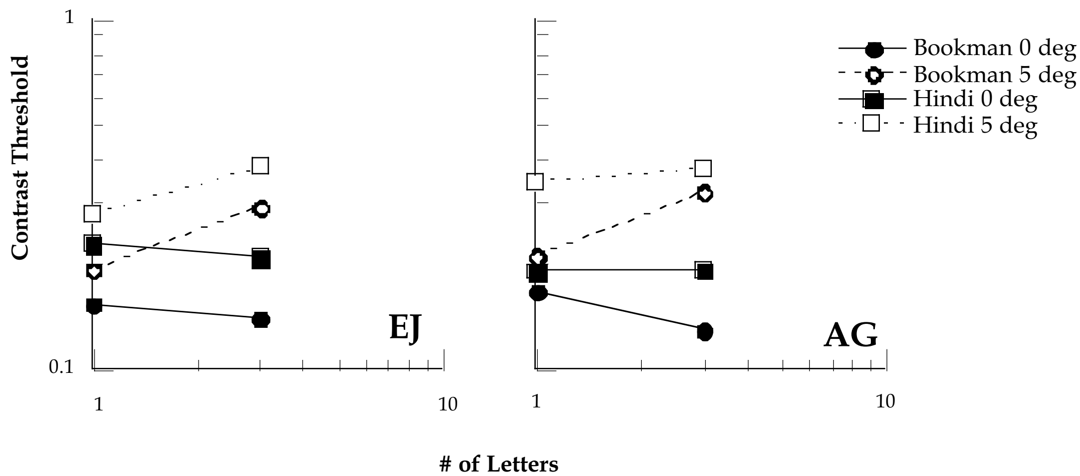


Figure 6: The number of letters refers to whether the stimulus was a single vowel (1) or a word (3). Contrast thresholds describe how luminous the signal has to be before it can be identified. It can be used to measure how well the observer fared in each part of the experiment- the lower the threshold, the better the observer performed. The open symbols indicate when the stimulus was shown at the fovea, the solid symbols indicate peripheral viewing. The circles represent the trials done in English and the squares represent trials done in Hindi. Observer EJ is illiterate in Hindi; observer AG is fluent in Hindi. Both are fluent in English.

The results are consistent with the predictions of crowding. The contrast threshold for words is higher than for letters in the periphery (where we expect crowding) but not in the fovea (where we don't expect crowding). This result is consistent across observers and for both alphabets. Since only AG can actually read Hindi, the results support the idea that crowding is independent of language.

The thresholds for the two observers were similar in all eight tasks, except for the Hindi vowel in the fovea. AG, the fluent Hindi reader, performed better than EJ in this task, presumably because she was more experienced in the alphabet than EJ.

DISCUSSION

Because the target letters in the words were the same letters in the single-letter trials, the basic task in all the experiments was to identify a single variable letter. Yet, contrast thresholds were significantly higher for words presented in the periphery, as predicted by the crowding hypothesis.

Both observers fared better with words in the fovea than single letters, which is puzzling. It was expected that in the fovea, performance on words would be similar to vowels, as AG demonstrated with Hindi, because crowding doesn't occur at the fovea. These results don't go against any aspect of the crowding hypothesis, but they do give evidence for the word-superiority effect.

The word-superiority effect (WSE) states that when a letter is presented in the context of a word in the fovea it is easier to identify (i.e. "cat" would have a lower threshold than "a"). EJ demonstrated the WSE in both Bookman and Hindi, while AG demonstrated the WSE in Bookman.

CONCLUSION

This study showed that when the flanks were spaced less than 1/2 the eccentricity away from the target letter, crowding was achieved. It is suspected that reading in the periphery is difficult because crowding occurs when the letters within a word are too close to each other.

The next step would be to see if crowding can be escaped by spacing out the letters in the words by more than half the eccentricity. A text taken from a book can be read through RSVP reading in the fovea and periphery, measuring reading rates at different presentation times. The letters in the words could then be spaced out to be greater than 1/2 the eccentricity to see if reading rate is accelerated.

Legge et al (1997) attributed the slowness of peripheral reading to the "shrinking visual span" hypothesis. Visual span is defined as the number of characters that are recognized in each glance and it is claimed that as eccentricity increased, the visual span decreased.

When letters are spaced out, the crowding theory predicts that peripheral reading speed will increase. However, the shrinking visual span theory predicts that it would be worse. It will be interesting to see what results come up from that experiment.

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REFERENCES

Bouma, H. (1970) Interaction effects in parafoveal letter recognition. *Nature, 241,* 177-178.

Brainard, D. H. (1997) The psychophysics toolbox. *Spatial Vision*, *10,* 433-6.

Chung, S.T., Mansfield, J.S., Legge, G.E. (1998). Psychophysics of reading. XVIII. The effect of print size on reading speed in normal peripheral vision. *Vision Research, 38,* 2949-2962.

Higgins, K.E., Arditi, A., & Knoblauch, K. (1996) Detection and identification of mirror-image letter pairs in central and peripheral vision. *Vision Research*, *36*, 331-335.

Latham, K., & Whitaker, D. (1996). A comparison of word recognition and reading performance in foveal and peripheral vision. *Vision Research*, *36*, 2665-2674.

Leat, S.J., Li, W. & Epp, K. (1999) Crowding in central and eccentric vision: The effects of contour interaction and attention. *Investigative Ophthalmology & Visual Science*, *40*, 504-512.

Legge, G.E. (1999). The visual span: a key concept for understanding reading difficulty in central-field loss. Talk given at Vision '99: International Conference on Low Vision, New York. July, 16 1999.

Pelli, D. G. (1997) The video toolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10,* 437-42.

Pelli, D.G., Burns, C.W., Farell, B., & Moore, D.C. (1999) Identifying letters. *Vision Research*. In press.

Rayner, K. & Bertera, J.H. (1979). Reading w/o a fovea. *Science, 206*, 468-469

Rubin, G.S., & Turano, K. (1994). Low vision reading with sequential word presentation. *Vision Research*, *34*, 1723-1733.

Toet, A. & Levi, D.M. (1992). The two-dimensional shape of spatial interaction zones in the parafovea. *Vision Research, 31*. 1315-1326.

Wolfe, J.M., O'Neill, P. & Benett, S.C. (1998). Why are there eccentricity effects in visual search? Visual and attentional hypotheses. *Perception and Psychophysics, 60*, 140-56.