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Text Density, Eye Movements, and Reading

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ABSTRACT

Variable width (often called *proportionally-spaced*) fonts pack more characters, and hence more information, into a line of text than do fixed width fonts. They are thus preferred by typographers, who use them as a means of fitting more text on fewer pages. Does this higher density result in faster or slower reading speeds?

We compared maximum reading speeds on a CRT using identical characters under three conditions of pitch: 1) fixed width (FW), each character centered in a constant horizontal space, 2) variable width (VW), characters occupying only the space required to eliminate overlap, and 3) modified variable width (MVW), average text density equated to that of the FW condition through the addition of inter-word microspace.

For small characters (close to the acuity limit), FW produced the fastest reading, with MVW yielding better performance than VW pitch, indicating two kinds of "crowding" effects: one interfering with individual character recognition and one interfering with word recognition. For medium and large characters (~0.25 to 6 deg height), performance was best with VW pitch, slowest with MVW pitch, and intermediate with FW pitch. Hence dense text packing may improve performance with all but the smallest characters. Control experiments using rapid serial visual presentation of text show that the higher text density and lower eye movement requirements of VW text are responsible for its superiority at medium and large character sizes.

1. INTRODUCTION

One of the most impressive aspects of reading skill is its relative immunity to variation in the reading stimulus. This wide variability allows typographers a great deal of flexibility in how text is printed. Although there has been a good deal of study of typography in reading[1], relatively little attention has been paid to density of characters. Given the typographer's common use of variable (also called proportional) pitch for reasons of economy, we wondered whether the higher horizontal character density of variable pitch resulted in better or worse reading performance than that of fixed pitch (commonly used in typewriters and computer terminals).

There are good reasons to believe both that it should be better and that it should be worse. On one hand, fewer horizontal reading fixations might be required to scan equivalent amounts of text with variable pitch. On the other hand, since characters may appear to run together and be less distinct, and since there is less certainty as to individual character location, reading might be expected to be more difficult with variable pitch. Our experiments examine the tradeoff between such factors.

To our knowledge, there has been only one previous study that has approached this issue. Beldie et al.[2] found variable pitch characters to provide significantly better performance in reading speed and proofreading, but he did not specify the character size he used. We will show in the experiments described below that the effect of pitch on reading performance depends critically on character size.

2. METHODS

2.1 Stimuli

Black text on a white background was generated by a Commodore-Amiga Model 1000 microcomputer and displayed on either an Amiga Model 1080 13 inch color monitor or a SONY Model 25XBR 25 inch color monitor, using either the Amiga version of Adobe Systems, Inc. Times-Roman font or a fixed width version

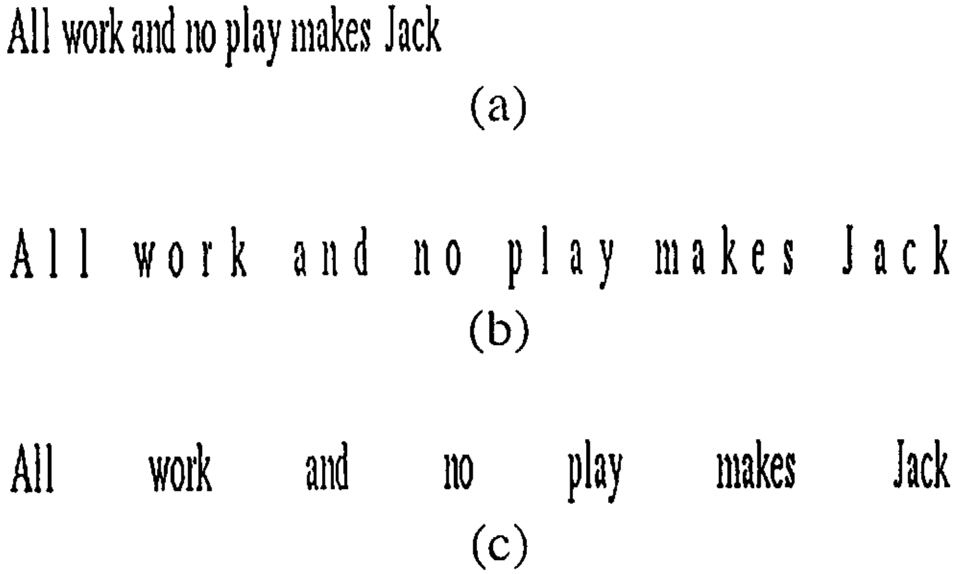

Figure 1 Replicas of the text we used, having the same number and shape of pixels as the 18-point font used in the experiments. a) variable width, b) fixed width, c) variable width modified to require the same total extent of eye movements as fixed width.

of that font which we created by adding space to thinner characters in order to make them each as wide as the widest character of the font set (the upper case "W"). The font size was nominally (with one exception, see below) 18-point (where a point refers to a vertical pixel).

Character size, expressed as the height of an upper case character, was varied by altering the viewing distance for character sizes in the range of .165 to 1.3 deg. For character heights smaller than .165 deg, a 9-point version of the same font was used in conjunction with the 13 inch monitor, while for character heights greater than 1.32 deg, the 25 inch monitor (with 18-point characters) set to matching background (48 cd/m^2) and foreground luminance (1 cd/m^2) was used. Viewing was binocular.

2.2 Procedure

Subjects were given ample practice on each condition. Testing was blocked by character size, with the set of character sizes run in a pseudo-random order. Within character size, the three text display conditions were pseudo-randomly permuted.

Reading material was obtained from standardized reading comprehension tests of roughly ninth grade level, and a variety of fiction and nonfiction sources of similar difficulty. Text was broken into lines consisting of the largest number of whole words that would fit a 35 character line.

A single line of text was displayed for a fixed duration in each trial, with a range of 3 to 8 words appearing in a line. The subject read the line out loud. If there were no errors in reading, the duration was decreased, until the subject began to make errors. Maximum reading rate was defined as the product of the proportion of correctly read words and the rate of text presentation in words per minute. The line length was intended to be short enough to recall from memory, eliminating ceiling effects imposed by limits in the rate of speech production, but long enough to require the scanning eye movements that are required in normal reading. Trials with 100% correct, with 50% or less correct, with fewer than 5 words on a line, or containing proper nouns, were discarded.

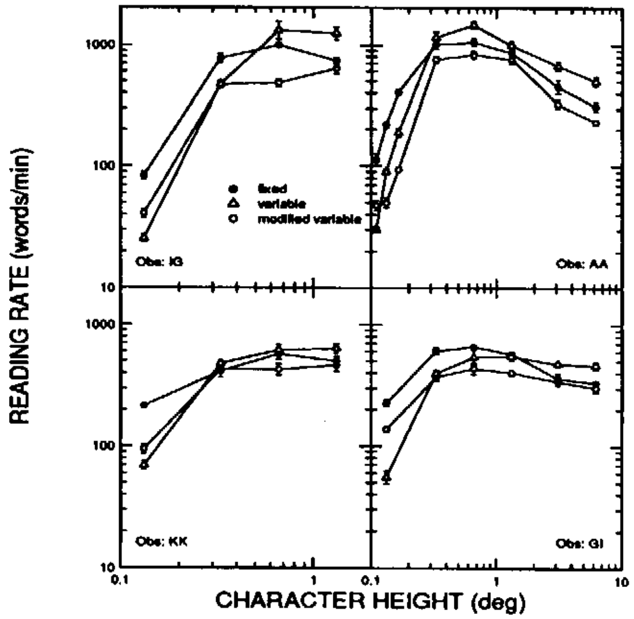

Figure 2. Reading rate as a function of character size, for four observers. Error bars represent 1 s. e. m. in this and succeeding graphs. Each point represents the geometric mean of at least 6 measurements.

The authors and several volunteers naive to the purpose of the experiments, served as subjects. All had Snellen distance acuity of 20/20 or better in both eyes (in some cases with simple lens correction), and otherwise normal vision except that one observer (KK) was color defective. While typical results are illustrated below, all major findings reported were replicated with naive subjects. Where the authors served as subjects, they were kept naive as to their performance until all testing was completed.

3. RESULTS

3.1 Reading with free eye movements

In this experiment, reading performance was assessed for text in three display modes: variable width (VW), in which characters occupy only as much horizontal space as is required to form them and prevent overlap; fixed width (FW), in which all characters are formed centered in a field as wide as the widest character in the character set; and modified variable width (MVW), in which words are displayed in variable width, but space is added between words to make line length equal to what it would be, were it displayed in fixed width. The MVW condition was added to control for differences in length of lines of equivalent content, and hence in the amount of horizontal eye movement required to scan a line of text. Figure 1 shows examples of the three display modes.

Figure 2 shows geometric means of reading rates for four observers as a function of character height, and display condition. All curves are of similar shape. Reading rate is low for small character sizes and increases with size, reaching a plateau throughout the mid-range of sizes, and tending to drop off slightly for the largest two sizes. This relationship between character size and reading rate is consistent with that reported using drifting text^{3,4}.

There are several points worth noting about the data. First, for medium and large characters, variable pitch text is read faster than either of the two other types of text. In this range of character sizes, then, typographic economy also seems to result in the most efficient reading.

Second, for small characters--small enough for reading rates to drop significantly, FW text is read fastest. The more rapid decline of performance with VW text as character size decreases is an example of "crowding," a phenomenon in which the presence of proximal contour elements is associated with reduced ability to identify what would otherwise be quite legible[5,6]. For character sizes close to the reading acuity limit, this crowding effect is strong enough to reverse the advantage variable pitch has over fixed pitch at medium and large character sizes.

Third, note that for the smallest character size at which each subject read, the MVW condition produced intermediate performance, indicating that the addition of space between words may improve performance with variable pitch, but not to the level observed when there is sufficient space between characters within a word as well. Hence there may be two separable crowding phenomena operating: one that makes word shapes less distinctive, and one that makes individual characters less distinctive.

While the results of this experiment consistently show a superiority of variable pitch with medium and large characters, they do not indicate that this superiority is entirely due to differences in line length between the VW and FW conditions. For although the FW and MVW conditions were equated in line length for equivalent text strings, the FW condition consistently produced faster reading than the MVW condition in all subjects in this range of character sizes. If differences in eye movement span are responsible for the difference between the FW and VW conditions, a different factor must be responsible for the difference between the FW and MVW conditions.

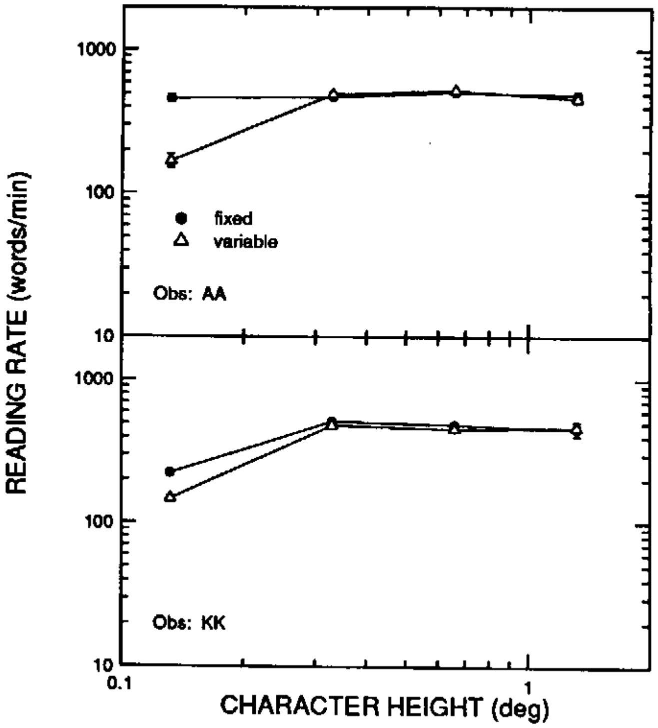

Figure 3 RSVP reading as a function of character size with central fixation for two observers.

3.2 Reading without eye movement requirements

Since the first experiment did not permit us to draw a firm conclusion on the role of eye movement requirements in the differences observed between FW and VW text, we decided to put the eye movement hypothesis to a further test by assessing reading rates under conditions that do not require such movements. We used the rapid serial visual presentation (RSVP) paradigm[7,8]. This technique involves presentation of text elements (in the present case, words) serially, at the same (centered) location on the screen. The procedure for this experiment was identical to that of Experiment 1, except that the word presentation rate rather than the line presentation duration was varied.

Results are shown in Figure 3. For small characters, the superiority of FW is undisturbed, indicating that crowding is still the constraining factor near the acuity limit. For medium and large characters, however, the data show clearly that without eye movement requirements, the superiority of VW over FW is eliminated. This is evidence that the shorter eye movement span required in reading VW text is directly responsible for the superior performance observed with VW reading for character sizes well removed from the acuity limit.

3.3 Eccentric reading without eye movement requirements

If eye movement span is responsible for the superiority of VW over FW in the medium to large character range, then what factors are responsible for the better performance of FW over MVW? Crowding alone cannot provide sufficient explanation since the VW condition, which yielded the best performance of all, should be at least as susceptible to crowding as the MVW condition. On the other hand, since crowding effects are known to be stronger with increasing eccentricity[9-11], and since there is considerable evidence that parafoveal characters to the right of fixation can influence normal reading[12,13], crowding within adjacent, eccentrically located words might be expected to produce substantially worse performance in the MVW than in the FW condition.

Consider the spatial relationships between characters and words in the MVW condition (see Fig. 1). When the reader makes a fixation to a new word, adjacent words fall peripheral to the fixation. Since in the MVW condition, the words have less space between characters than they do in the fixed pitch condition, these adjacent words should be less identifiable due to the greater susceptibility (of eccentric retina) to crowding than should the fixed pitch words. In addition, the nearest character of the adjacent word is more peripheral in the MVW than in the FW condition, which would further foster crowding. Eccentric crowding, of course, should operate on VW text in exactly the same way, at the same eccentricity. However, because of its more compact representation, in that condition, more text is available to the reader within the window of high acuity and low susceptibility to crowding, resulting in the need for fewer fixations per line.

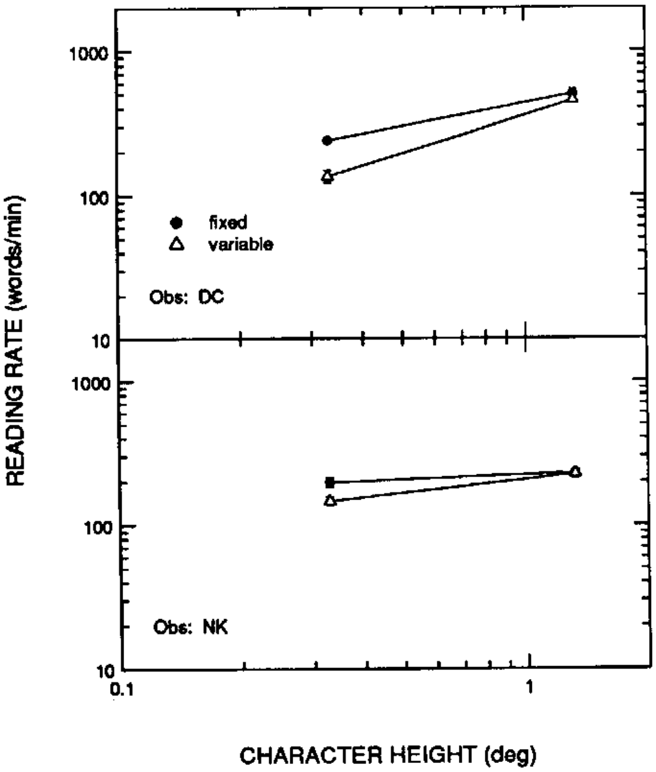

Figure 4 RSVP reading as a function of character size for words presented at 2 deg eccentricity.

In order to confirm that reading with eccentric retina results in increased crowding with our particular stimulus, we measured RSVP reading rates with 2 deg eccentric viewing. As a fixation control, words were presented randomly either 2 deg above or below a fixation point to discourage eye movements to an expected word location. Words were vertically rather than horizontally displaced because 2 deg horizontal displacement in a pilot experiment had produced a strong compulsion to fixate the flashed words, resulting in an inaccurate measure of performance.

The results, shown in Figure 4, display evidence of crowding for the smaller but not the larger character size. Like the centrally fixated RSVP results, crowding depends on character size, but in these data, crowding occurs at a character height (0.33 deg) in which no crowding was observed with central fixation. These data are consistent with the idea that central and eccentric RSVP reading differ only with regards to scale.

3.4 Reading scrambled text

While the greater average eccentricity of adjacent words interferes with reading performance of MVW text, another factor, at a more cognitive level, might be operating also. It is possible that the greater separation between words in MVW text interferes with the reader's ability to group words into phrases or other multi-word units. Such groupings may facilitate reading by providing better contextual cues for word identification. Even though our instructions to subjects stressed that speed and accuracy be paramount, such cues probably played a significant role in reading performance, nevertheless.

To evaluate whether the added inter-word space of MVW text influenced reading by interfering with comprehension, we compared reading performance for MVW and FW text when the word order of our text stimulus files was scrambled. All punctuation and word capitalization was preserved. Randomized word order would destroy phrase structure in the sentence and, thus, would penalize any mechanism that depended on grouping sentence elements into meaningful chunks.

Figure 5 shows the difference between the logarithms of the reading rates for FW and MVW text for scrambled and unscrambled text for two subjects. For unscrambled text (filled circles), the difference was greater than zero, indicating the original effect, that FW text is read faster than MVW text. At the character heights measured, FW text was read on average about 28% faster than MVW text. For scrambled text (unfilled triangles), however, the differences between the reading speeds were reduced to near zero. On average, the reading speeds for the two types of text differed by less than 2% when the text was scrambled. These results, then, are not inconsistent with the notion that a mechanism that partitions a sentence into groups of words on a grammatical basis participates in the processing of text for reading and that interference with such a mechanism, also, contributes to the difference in reading rates between FW and MVW text.

4. DISCUSSION

These experiments suggest several points of significance in applied vision contexts. First, they show that the optimal choice of fixed vs. variable pitch presentation in displays designed for rapid reading requires knowledge of the angular size of the characters presented, since predictions based on small and large characters are quite opposite. Second, effects on reading speed of pitch can be quite sizable, ranging from, with our stimuli, about 300% for the smallest characters, to about 60% for medium and large characters. Third, examination of Figure 2 shows that there is considerable inter-observer variability in the character size where one presentation mode crosses from being inferior to being superior. Hence, as a practical matter, only the cases of very small and fairly large characters produce clear predictions.

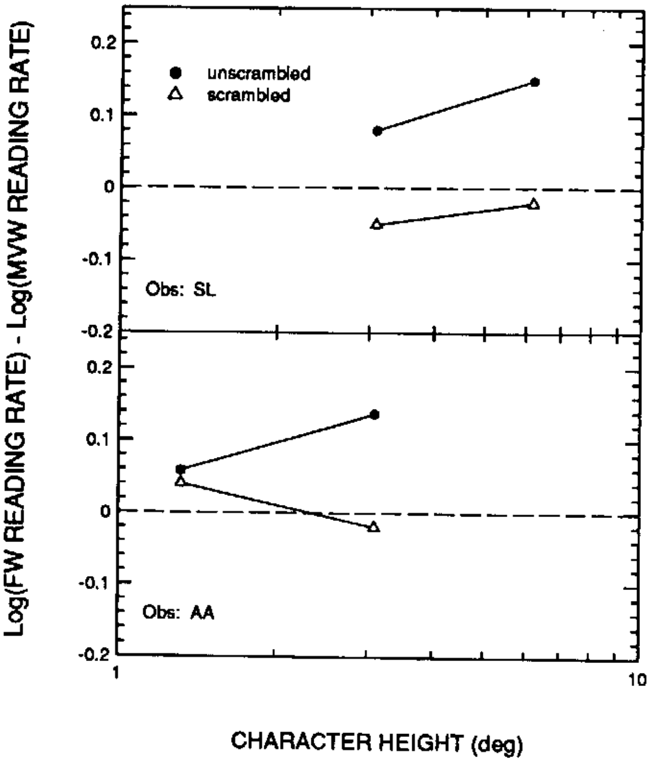

Figure 5 The effect of word order on the difference in log reading rates between FW and MVW text.

In the area of clinical vision science, a promising area for future investigations of character pitch is in low vision, where the differences observed here may possibly determine whether or not an individual can read at all. Many such individuals must read text near their acuity limit due to retinal image degradation, or to central visual field loss. Individuals with central loss might be expected to read fixed pitch fonts more easily due to the greater susceptibility of crowding effects of the eccentric retina with which they must read, and indeed, preliminary data we have collected with such individuals indicate this. On the other hand, their difficulty in making fixative eye movements in reading should favor the greater compression of variable pitch. Other low vision patients, reading highly magnified text, might benefit from the increased positional certainty of characters of fixed pitch.

One important issue that this study has not addressed, is the relative extent to which observed differences in performance between fixed and variable pitch are due to differences in regularity of pitch, as opposed to differences in closeness of spacing. Because crowding effects are easily observed with single characters flanked by crowding contours, closeness of spacing would seem to provide the most parsimonious explanation. In addition, there has been at least one report[14] of closely spaced text providing a slight advantage in reading speed relative to regular letter spacing.

For basic models of reading, our data suggest that the following effects must be considered: retinally central crowding of individual characters by neighboring characters and of words by adjacent words, number of eye fixations required to scan the text, and possibly, crowding of more eccentrically located words that may not exhibit crowding in central vision at small sizes. More specifically, we see ability to resolve characters and words as the primary determinants of reading performance for small characters, and rate of information processing as dictated by eye movement and cognitive factors, as determining performance for medium and large characters.

5. ACKNOWLEDGMENTS

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Ilana Grunwald is also affiliated with the Department of Psychology of Queens College, Flushing, NY.

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