Reading with fixed and variable character pitch

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We compared the effects of fixed and variable (proportional) spacing on reading speeds and found variable pitch to yield better performance at medium and large character sizes and fixed pitch to be superior for character sizes approaching the acuity limit. The data indicate at least two crowding effects at the smallest sizes: one that interferes with individual character identification and one that interferes with word identification. A control experiment using rapid serial visual presentation suggests that it is the greater horizontal compression and consequently reduced eye-movement requirements of variable pitch that are responsible for its superiority at medium and large character sizes.

INTRODUCTION

One of the most impressive aspects of reading skill is its relative immunity to variation in the reading stimulus, permitting efficient processing of widely diverse types of material, including virtually infinite varieties of handwritten and printed text. Although the nature of the reading process has been studied for many years, the contemporary psychophysics literature has paid little attention to typographic stimulus factors, although they are known to affect reading performance.[1] In the study reported here we examined the effects on reading of a simple manipulation used to print text material more economically: character spacing, or pitch.

Most printed material today uses variable (also called proportional) spacing. With this type of pitch, the amount of horizontal space that a character occupies depends on the width of the individual character, so that an i takes up much less space than a w. With fixed pitch, on the other hand, all characters occupy the same amount of horizontal space. In order that the characters never overlap, this amount has to be at least as great as that of the widest character, usually the uppercase W. Fixed pitch is used today primarily in computer display terminals and typewriters but may disappear as these technologies advance to permit the use of variable pitch, which in addition to being more spatially economical is thought to be more aesthetically pleasing.

The horizontal compression of variable pitch certainly results in typographic economy, but does it affect reading efficiency? On one hand, more characters per fixation potentially can be processed with variable pitch than with fixed pitch since more characters will fall within a region of high visual acuity.[2] On the other hand, the proximity of the characters to one another with this type of pitch may increase difficulty in differentiating them and thus interfere with character and word identification.

To our knowledge, there have been only two studies that have approached this issue. Payne[4] compared reading speed and comprehension with a fixed- and a variable-width typewriter font. However, these fonts differed in character size and line spacing as well as in pitch, and viewing distance was not specified. Beldie *et al.*[5] found that variable-pitch characters provide significantly better performance in reading speed and proofreading but did not specify the character size used. We show in the experiments described below that the effect of pitch on reading performance can depend critically on character size.

METHODS

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-in. (33-cm) color monitor or a Sony Model 25XBR 25-in. (63-cm) color monitor, using either the Times Roman font supplied with the Amiga system software (version 1.3) or a fixed-width version of that font that we created by adding space to thinner characters in order to make each of them as wide as the widest character of the font set (the uppercase 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 uppercase character, was varied by altering the viewing distance to the 13-in. monitor for character sizes in the range of 0.165 to 1.3 deg. For character heights smaller than 0.165 deg, a 9-point version of the same font was used in conjunction with the 13-in. monitor, whereas for character heights greater than 1.32 deg the 25-in. monitor (with 18-point characters) set to matching background (48 cd/m^2) and foreground (1 cd/m^2) luminance was used. Viewing was binocular.

Procedure

Subjects were given ample practice on each condition. Testing was blocked by character size, with the set of character sizes run in a pseudorandom order. Within character size, the three text display conditions were pseudorandomly 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 three to eight words appearing in a

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All work and no play makes Jack

(a)

A l l w o r k a n d n o p l a y m a k e s J a c k

(b)

All work and no play makes Jack

(c)

Fig. 1. Replicas of the text that we used, having the same number and shape of pixels as the 18-point font used in the experiments: (a) VW, (b) FW, (c) VW modified to require the same total extent of eye movements as FW. These text images may appear more jagged here than in our viewing conditions because this rendition removes the inherent fuzziness of the cathode-ray tube, which has an antialiasing effect.

line. The subject read the line aloud. If there were no errors in reading, the duration was decreased until the subject began to make errors. The 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 be recalled 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 five words on a line, or containing proper nouns, were discarded.

The authors and several volunteers naïve 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 naïve subjects. Where the authors served as subjects, they were kept naive about their performance until all testing was completed.

RESULTS

Experiment 1: Reading with Free Eye Movements

In the first 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

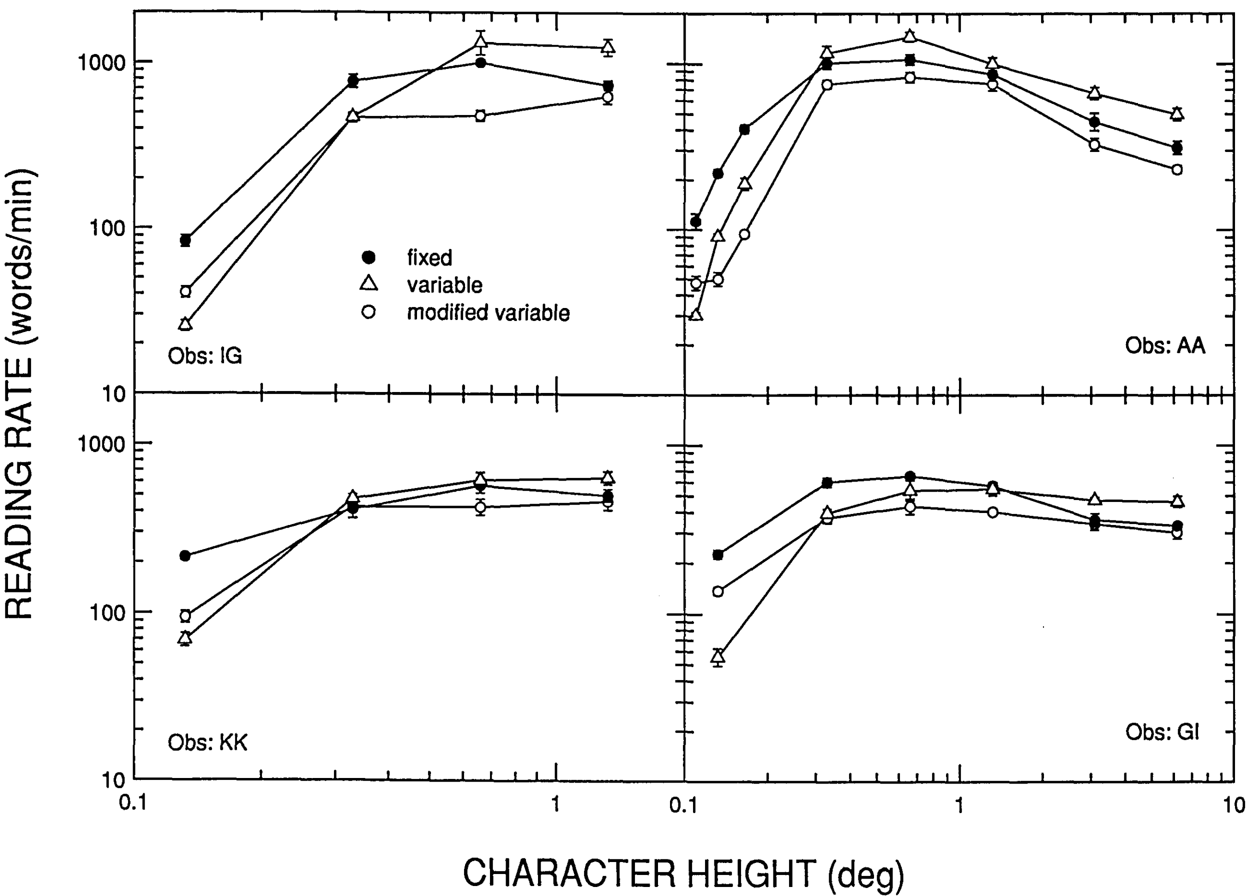

Fig. 2. Reading rate as a function of character size for four observers. Each error bar represents 1 standard error of the mean in this and succeeding graphs. Each point represents the geometric mean of at least six measurements. For reference, a character height of 0.47 deg on this graph has the same angular size as 12-point (in conventional 1/72-in. typesetting units) Times Roman viewed at 40 cm.

variable width but space is added between words to make line length equal to what it would be if it were 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 in order 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 midrange 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 when drifting text was used.[6,7]

There are several points worth noting about the data. First, with large characters for all subjects, and medium-sized characters for three of the four subjects shown, variable-pitch text is read faster than either of the two other types of text. For these 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—fixed-pitch test 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.[8,9] For character sizes close to the reading acuity limit, this crowding effect is strong enough to reverse the advantage that 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.

Although 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 conditions consistently produced faster reading than the MVW condition did 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.

Experiment 2: Reading without Eye-Movement Requirements

Since reading MVW text may be more difficult than reading FW text for reasons other than eye-movement requirements, 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.[10,11] This technique involves presentation of text elements (in the present case, words) serially, at the same (centered) location on the

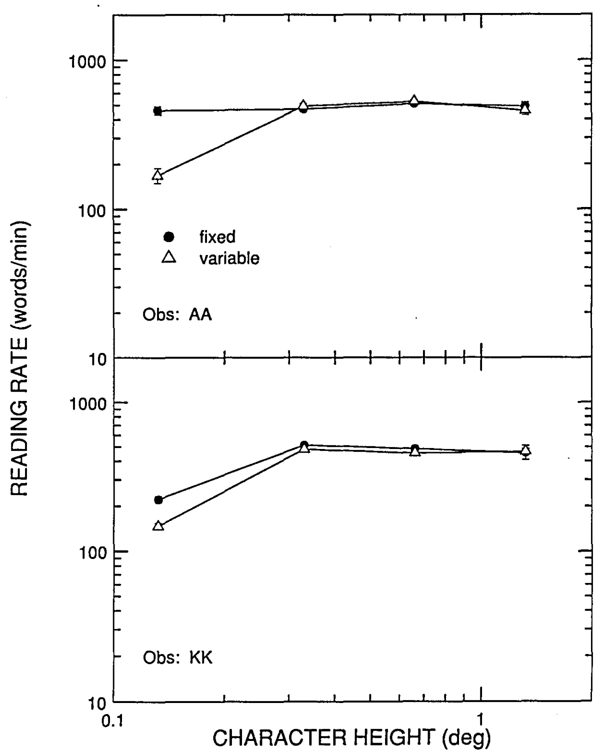

Fig. 3. RSVP reading as a function of character size with central fixation for two observers.

screen. The method 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 Fig. 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.

It should be noted that the RSVP reading speeds that we obtained here are slower than those that we obtained in Experiment 1 but are about twice as fast as those that we obtained previously with drifting text under similar conditions[7] and that have been reported by Legge *et al.*[6] Although many readers can read as fast or faster with RSVP as with some forms of spatially extended text,[12] the relationship between presentation method and reading speed is beyond the scope of this paper.

Experiment 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 a 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,[13–15] and since there is considerable evidence that parafoveal characters to the right of fixation can influence normal reading,[16,17] crowding of adjacent, eccentrically located words might be expected to produce substantially worse performance in the MVW than in the FW conditions.

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 peripherally 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 readily identifiable owing 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.

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 a highly erratic measure of performance. The increased uncertainty of word location made the task more difficult but allowed us to assess reading speeds accurately.

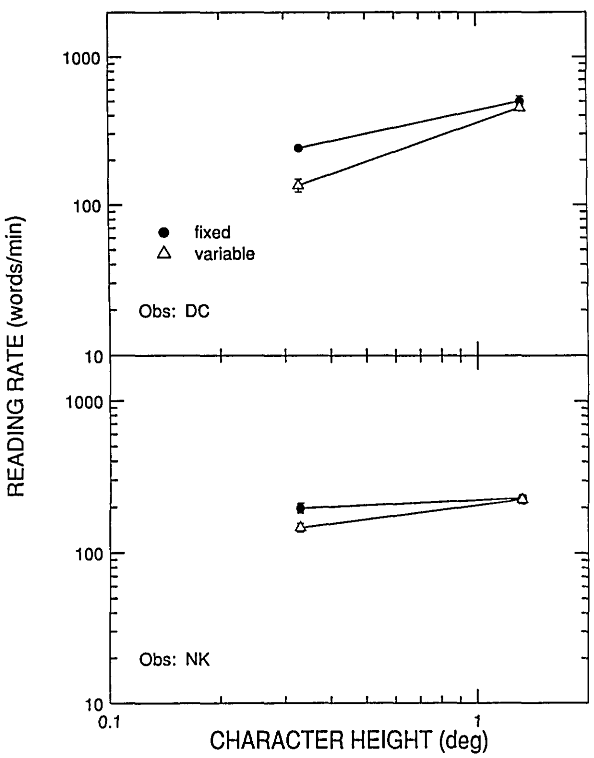

Fig. 4. RSVP reading as a function of character size for words presented at 2-deg eccentricity.

Results for two observers, shown in Fig. 4, display evidence of crowding for the smaller but not for the larger character size. As for 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.

GENERAL DISCUSSION

These experiments suggest several points of significance in applied-vision contexts. First, they show that the optimal choice of fixed- versus variable-pitch presentation in displays designed for rapid reading may require knowledge of the angular size of the characters presented, since predictions based on small and large characters can be opposite. Second, effects on reading speed of pitch can be quite sizable, ranging, with our stimuli, from ~300% for the smallest characters to ~60% for medium and large characters. Third, examination of Fig. 2 shows that there is considerable interobserver 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 with the fonts that we used. Because we examined performance with only a single font, however, these results should be interpreted with caution. Differences in character aspect ratio and closeness of spacing of variable-pitch text might also be expected to influence absolute and relative reading performance.

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 an individual can read at all. Many such individuals must read text near their acuity limit because of retinal image degradation or central visual field loss. Individuals with central loss might be expected to read fixed-pitch fonts more easily owing to the greater susceptibility of crowding effects of the eccentric retina with which they must read. 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. Our preliminary results with individuals with macular disease show fixed pitch to be far more readable for most subjects at the character size at which they read most comfortably.

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[18] that closely spaced text provides 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 in order to scan the text, and, possibly, crowding of more eccentrically located words that may not exhibit crowding in central vision at small sizes.

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