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ABSTRACT

This study investigated the effect of two classes of variables on a person's performance: the size of the window within which normal text was displayed and the type of information present in the display beyond the boundaries of the window. Six junior and senior high school students, identified as being among the best readers in their school, were used as subjects. Each subject read sixteen 500-word passages taken from a high school psychology text. Each passage was divided into six pages, displayed a page at a time, double-spaced, for the reader. Six mutilated versions of the passages were also prepared. For two of these versions each letter or number was replaced with an X. For two versions each letter or number was replaced with a letter or number which tended to be visually confusable with it. In the final two versions each letter or number was replaced with a letter or number not usually confused with it. Eight window sizes were used: 13, 17, 21, 25, 31, 37, 45, or 100 character positions on the line fixated. Results indicated that there is a clear effect due to window size. Reducing the window to thirteen characters increases the fixation duration by 30 percent, decreases the saccade length for forward saccades by 26 percent, and increases reading time by 60 percent, as compared to a window size of 100 character spaces. (WR)

The Span of the Effective Stimulus During Fixations in Reading[1,2,3]

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R.S. Woodworth, in his 1938 review of research in reading, entitled one section "How much can be read in a single fixation?" The investigation of this question has a long history, all with equivocal results. If a person fixates a letter on a page of text, he often finds that he can recognize words two or even three lines above and below the line being fixated, as well as words some distance to the left and right. Beyond that, punctuation marks, capital letters, and beginnings and ends of paragraphs are visible. On the other hand, if a string of random letters is presented visually by means of a tachistiscope, a person is likely to be able to identify only four to six letters. Somewhere between these extremes lies the size of the perceptual span during a fixation while reading.

The techniques used to investigate this question have either not involved a normal reading task at all, as when subjects try to report a letter string or a few words presented tachistiscopically, or they have placed severe restrictions on the person's normal reading, as when subjects read under conditions where successive portions of the text are presented to them at a rate determined by the experimenter (Poulton, 1962; Newman, 1966).

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[1]This paper was presented at the 1973 meetings of the American Educational Research Association, held in New Orleans, Lousiana.

[2]Copies of this paper may be obtained by writing to Dr. George W. McConkie, Department of Education, Cornell University, Ithaca, New York, 14850.

[3]The research reported here was carried out at the Artificial Intelligence Laboratory at Massachusetts Institute of Technology, Cambridge, Massachusetts, while the senior author was on a Special Fellowship from the National Institutes of Health. It was supported by a grant from the U.S. Office of Education under the Basic Research in Education program. Special thanks are extended to Dr. Marvin Minsky for providing the authors with the opportunity to conduct this research, to David Silver, staff programmer at the Artificial Intelligence Laboratory, for much of the programming involved, and to Gary Wolverton for assisting with the analysis of the data.

The research to be reported here was an attempt to develop a method of getting information about the perceptual span in a situation involving normal reading, with as few constraints on the reader as possible. Essentially, we attempted to devise a means of discovering how far into the periphery a reader picks up specific types of visual information which are of use to him in his reading.

The technique used to research this question involved the development of an Eye-Movement Controlled Display System. This was accomplished by programming a computer to display text on a cathode-ray tube (much like a television tube), and to track a reader's eyes as he reads from the text. Eye tracking was accomplished by means of a Biometrics Type SG Eye Movement Monitor, with the computer sampling its signal 60 times per second. With this system it is possible to make rapid changes in the display from which a person is reading, at specific locations with regard to his point of fixation.

The general approach in this research involved taking text which subjects were to read, called the Original Text, and making various types of mutilations of it by replacing characters in the original text with certain other characters. In one condition, for example, each letter was replaced by an x, thus destroying the readability of the text but maintaining information about word length and punctuation. Both the original text and the mutilated version were stored in the computer. At first, the mutilated text was displayed on the cathode-ray tube. However, when the reader fixated the first line, the display was immediately changed so that within a certain boundary (say, eight character spaces to the left and right of the fixated character) the x's were replaced by corresponding letters from the original text. This area within which normal text was will be called the window. When the person made a saccade, those letters became x's once again, and the x's within the window area around his new fixation point were replaced by the corresponding letters from the original text. Thus, wherever the reader looked there was a window of normal text for him to see, but the size of that area was set by the experimenter. Also, the experimenter was able to specify just what aspects of the original text were present in the reader's periphery, by preparing mutilations of the original text in specific ways. In the present example, the reader had word length and punctuation information in his periphery, but not information about any other aspect of the words or letters.

Essentially, this experimental situation can be viewed as one in which the experimenter has the capability of deleting certain aspects of the normal visual information from the display, at certain regions in the person's visual field. It is assumed that if the information which is removed is information the person normally uses in reading, this should result in some sort of change in the person's reading behavior; generally a reduction in his reading efficiency. Examples of such a change include longer reading time, poorer performance on questions, longer fixation durations, shorter saccades, etc. On the other hand, if the information removed is not normally used in reading, we would expect its deletion to have little or no effect on reading. Thus, the strategy is to program the computer to make certain types of changes in the visual display on each fixation as the person reads, and then to examine the indices of reading behavior to see if that type of change produces a change in his reading behavior.

The present study investigated the effect of two classes of variables on the person's reading performance: the size of the window within which normal text was displayed, and the type of information present in the display beyond the boundaries of the window.

Method

Subjects. Six high school students participated as subjects in this study. All were juniors or seniors and were identified as being among the best readers in their school. They were paid for participation. All had participated in an earlier study and were familiar with the equipment and procedures used.

Materials. Each subject read sixteen 500-word passages taken from a high school psychology text. Each passage was divided into six pages, displayed a page at a time, double-spaced, for the reader. Six mutilated versions of each passage were also prepared. These actually conformed to a two by three design. Three algorithms were used for substituting characters for the letters in the original text. For two of these versions, called the x versions, each letter or number was replaced with an x. For two versions, each letter or number was replaced by a letter or number which tended to be visually confusable with it. In addition, ascenders were replaced with ascenders, decenders with descenders, etc. These were called the Compatible (C) versions. This form of mutilation maintained the external word shape of each word, as well as certain features of the original letters. In the final two versions, each letter or number was replaced with a letter or number not usually confused with it. In fact, ascenders and descenders were replaced by letters not having these characteristics, and vice versa. These were called the Non-compatible (NC) versions. In addition, one version of each pair was left as just described, with spaces and punctuation remaining, and was called the Spaces (S) version. In the other, appropriate letters were used to replace the spaces and punctuation marks. Thus, in the X Version, they were replaced by x's; in the others, by other letters. These were called the Filled (F) versions. Information about beginning and ends of lines still remained in these versions. In all, then, there were six versions of mutilations prepared for each passage: XS, XF, CS, CF, NCS, NCF.

Design. Each subject read all sixteen passages (96 pages), with one page of each passage being replaced by each of the six mutilated versions of the original display. Eight window sizes were used: 13, 17, 21, 25, 31, 37, 45, or 100 character positions on the line fixated. With a window size of 13, the person could see the character on which he fixated and the six adjacent characters to either side. Fixations near the end of the line reduced the width of original text displayed; in effect, the window extended beyond the end of the line. All pages of a passage were read with a single window size by a subject. The eight window sizes and six mutilation versions produced 48 experimental conditions, with each subject reading two pages under each condition, one in the first eight passages and one in the second. Passages were read in the same order by all subjects, and other variables were counterbalanced as far as possible.

Procedure. When a subject arrived for the experiment, a bite bar was prepared for him which served to reduce head movement during the experiment. Then the eye tracking sensors, mounted on glasses frames and held more securely with a head band, were placed on him and adjusted. The nature of the display changes was explained, and he was instructed that his task was simply to read the passages to understand them; he would be tested after each, and would receive extra pay according to the number of questions he answered correctly. He then read several pages for practice, until he felt comfortable in the situation. At that point, the first test passage was displayed, and he began the experimental sequence.

Prior to reading each passage, the subject was engaged in a calibration task. A target spot appeared on the display, the subject looked directly at it and pushed a lever. Then the target moved to a new position and the action was repeated. This sequence occurred 25 times. When completed, an additional push of the lever caused the display of the first page of the passage, and additional pages were also obtained by depressing the lever. As the subject read each page, the computer kept a complete record of the position and duration of each fixation, and the time required for each saccade. All times were recorded in 60ths of a second. After reading the last page of each passage, the subject came off from the bite bar and was given a test with 12 short-answer questions, two from each page of the text. Most questions tested retention of details clearly stated in the passage. After his answers were checked and he was told his score, he again positioned himself on the bite bar, went through the calibration procedure and read the next passage. The actual experiment, excluding equipment adjustment, required about two hours per subject. For most subjects, this was split into two testing sessions.

Technical details. The study was carried out using a PDP-6 computer, a 36-bit word machine with 32 K of core memory operating as a single-user system, interfaced with a PDP-10 time-sharing system. The

PDP-10 did all file handling, reading in passages as needed, and accepting the data.

The display scope was a Digital Equipment Corporation Model 340, which has a character generator for upper and lower case letters. It has P-7 phosphor, and a blue filter was used to filter out the yellow persistence, thus producing a rapid decay of the image, allowing very crisp display changes to take place. The scope will display 40 lines of 80 characters each in an area of 8 1/4 by 7 1/4 inches. The pages of text displayed were typically of about five or six lines, double spaced, approximately 70-75 characters each. The subject's eye was about 21 inches from the display, so a line of text occupied about 18 degrees of visual angle.

The program sampled the reader's eye position 60 times per second, and identified the eye as being in one of two states. If the change in position since the last sample was less than a certain (adjustable) threshold, the eye was said to be fixated; if greater, it was said to be in movement. An attempt was made to adjust the threshold for individuals, to keep it as low as possible, but at the same time to reduce to a minimum the number of state changes registered during what appeared from a plot of the eye movements to be best identified as single fixations.

The technique used in the experiment was to monitor the eye during a saccade, waiting for the rate of movement to fall below the threshold. When this happened, a fixation was declared, and the eye position was taken as the fixation location for that fixation. The display was immediately turned off, changes were made in the display list to place the window at the desired location, and the display was then turned back on. The time the scope was off depended upon the size of the window. It ranged from about five milliseconds with a 13 character window, to 30 milliseconds with a 100 character window. The flicker produced with the smaller windows was not noticeable, but with the larger windows (45 and 100 characters) it was very apparent.

This particular program, then, had the characteristic that it minimized the amount of display change taking place during a fixation; even if the eye drifted somewhat during a fixation, the display usually remained constant until an actual saccade was made.

Results and Discussion

For each page of text read by each subject, summary statistics were obtained including reading time per hundred characters, number of regressive movements per 100 characters, median saccade lengths for forward saccades as well as first and third quartiles, median fixation duration as well as first and third quartiles, and number of fixations per 100 characters. This gave him scores for each page read. For each of these variables, the data were subjected to a series of analyses of variance, one for each window size. Each was a three-factor analysis: spaces vs. filled, type of mutilation, and subjects (2 x 3 x 6). The subjects variable was almost always significant, for all variables and window sizes, but seldom interacted with the other variables. Most of the other significant effects can be seen in figures 1, 2, 3, 4, and 5, which include 12 of the 17 significant ($p < .05$) main effects obtained. There were also six significant interactions not involving subjects, but there was no clear pattern to these and they will not be discussed further.

For all variables except number of regressions, there is a clear effect due to window size. Reducing the window to 13 character spaces increases the fixation duration by 30%, decreases the saccade length for forward saccades by 26%, and increases reading time by 60%, as compared to a window size of 100 character spaces. For most variables the curves do not appear to reach asymptote until a window size of 45.

The type of mutilated text in peripheral vision primarily affected fixation duration, and presence or absence of spaces primarily affected saccade length (together with number of fixations per 100 characters, which is not presented here). Both variables had an effect on the frequencey of regressive movements.

Ignoring the data on the frequency of regressive movements for a moment, several patterns are seen in the remaining data. Figure 1 indicates that maintaining word shape in the text outside the window facilitates reading with the two smallest window sizes, but this effect disappears at window size 21. Apparently external word shape information is not utilized further than about nine character spaces away from the point of fixation. Having x's outside the window produces shorter durations through window size 21, but not at 25. With x's in the periphery, it is very obvious where the boundary of the window is; with the other two conditions, there is no such indicator. Thus, in the x condition, there is less tendency to attempt to integrate wrong letters outside the window into words. The superiority of the x condition at window size 21 seems to indicate that subjects are still picking up letter information 10 or 11 characters away from the fixation point. At 12 characters away, however, there is no evidence for the pickup of either letter or word shape information; that is, the x condition is no different from the other two conditions.

Turning to Figures 2 and 3, which show the means for the median saccade lengths and for the third quartiles, the influence of having word spaces in peripheral vision can be seen. Forward saccades were longer with spaces than without. This effect seems to be greater at the third quartile than at the median (and was absent at the first quartile) indicating that the main difference is in the number of long saccades occurring; they are more frequent with spaces indicating word boundaries. It is difficult to say when this effect vanishes; though not statistically significant, small differences in this direction are found at every window size smaller than 45.

It is clear, then, that word length information is affecting reading farther into the periphery than is word shape or specific letter information, and that it is used in determining where to send the eye.

Figures 4 and 5 show the effect of the independent variables on the frequency of making regressive eye movements. These data are much less stable, but trends are persistent: there are more regressive movements when the display outside the window maintains word shape, less when it destroys it, and is least with x's. Also more regressions occur when boundaries between words in the periphery are marked by spaces than when these spaces are filled. The former effect is particularly prominant at the smaller window sizes, and the latter at the larger sizes. The interpretation of these data is unclear at present, but they serve as a warning that the variables studied may have an effect on reading farther into the periphery than was suggested on the basis on an analysis of fixation durations and saccade lengths.

Since the curves relating saccade length, fixation duration, reading time, etc., to window size only reach asymptote at a window size of 45 character spaces, one might be tempted to conclude that subjects are actually utilizing information from 22 character spaces to left and right of their fixation point during a fixation. However, the previous analysis questions such a conclusion. If subjects are not obtaining word shape or specific letter information beyond about ten character spaces from the fixation point, and if the influence of word length information is quite small at 12 and 15 character spaces away, there seems to be no other type of information left in the original text which the subject could be obtaining at that distance to facilitate his reading. We tend to believe that there is something distracting about the task itself that interferes with reading at the smaller window sizes. It may be that the display is not being changed fast enough after the eye fixates, for instance, producing a slightly distracting flash as the stimulus changes take place. With larger window sizes, these changes are taking place further into the periphery where they are less distracting. If this is the case, finding ways of speeding the display change may result in an earlier asymptote in the data curves.

From the saccade length and fixation duration data, it appears that good readers actually pick up letter and word shape information from a rather limited area during a fixation, only about 17 to 19 character spaces at the most.[4]

[4] This statement assumes, of course, that the reader picks up information equally far to left and right of the fixation point. Some of our recent data suggests that this may be incorrect. If so, the region from which letter and word shape information is acquired during a fixation may be even smaller.

Obviously further research is needed on this question, including a careful examination of effects which stimulus change per se during reading have on a person's reading behavior, Such research is necessary to insure that the results obtained are not simply produced by artifacts of the stimulus situation.

A word should be mentioned about one other aspect of the data. The performance on test questions has not yet been evaluated for this study. However, a prior study was conducted much like the present one, in which the smallest window size used was 9 characters. This has the effect of forcing a person to be a word-by-word reader, and not allowing him to input larger units during a fixation. It is of particular interest to observe, then, that although a small window produced much slower reading, it had no effect on test performance. This finding contradicts the notion that poor readers fail to comprehend because they see only a word at a time, thus forcing them to process smaller units and overloading their short-term memory capacity (for instance, see Smith, 1971). Forcing a good reader to read with a very small perceptual span, though it slows him down, does not deteriorate his understanding and retention of the information in the passage. It may be that poor readers have a smaller perceptual span, but this cannot be taken as the cause of their failure to comprehend and retain information from the text.

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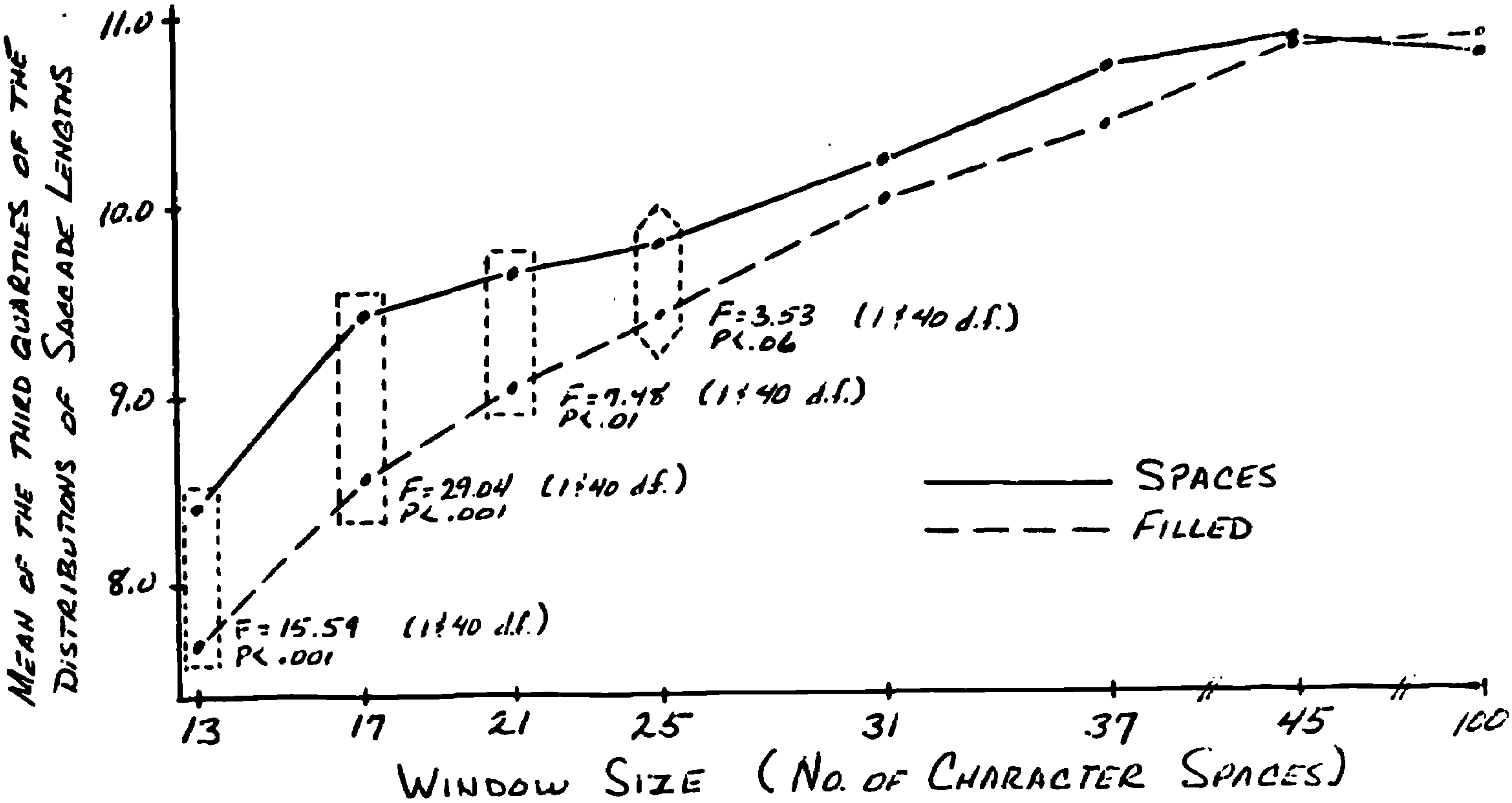

Figure 3 - Means of the third quartiles of the distributions of saccade lengths plotted by window size. Space and filled conditions are plotted separately. Significant differences are indicated.

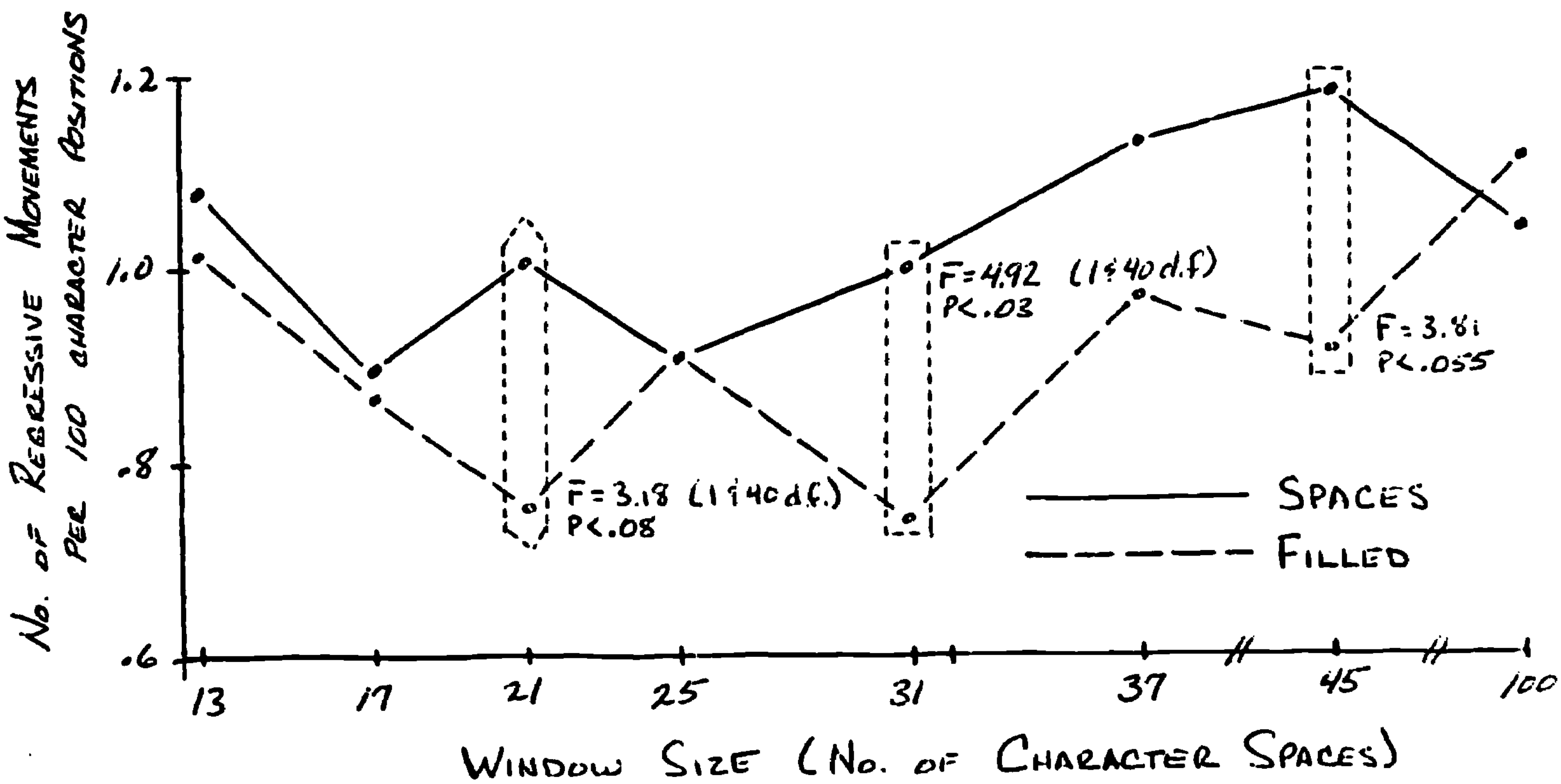

Figure 4 - Number of regressive movements per 100 character positions, plotted by window size. Space and filled conditions are plotted separately. Significant differences are indicated.

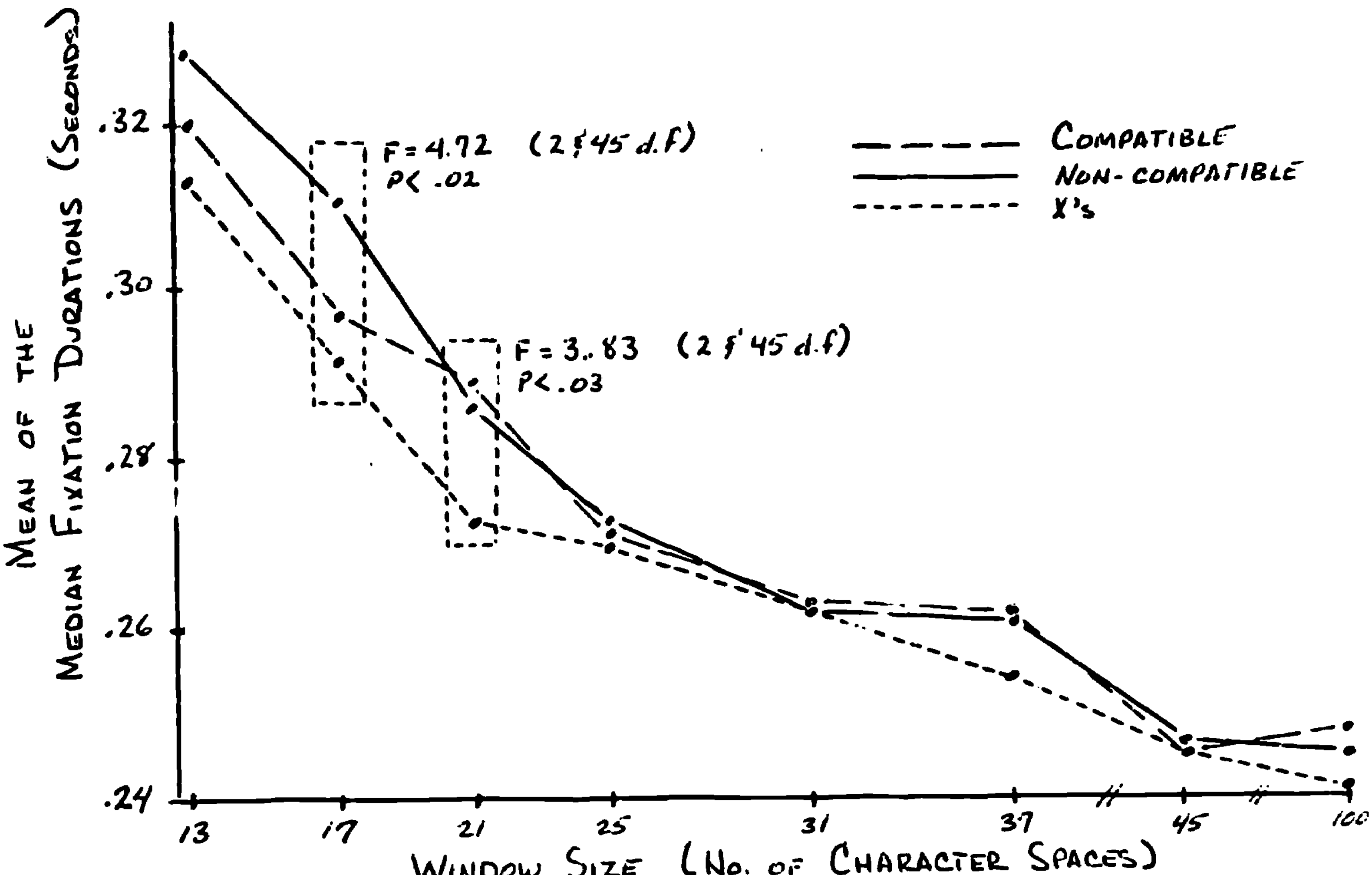

Figure 1 - Means of the median fixation durations, plotted by window size. Different text mutilation conditions are plotted separately. Significant effects are indicated.

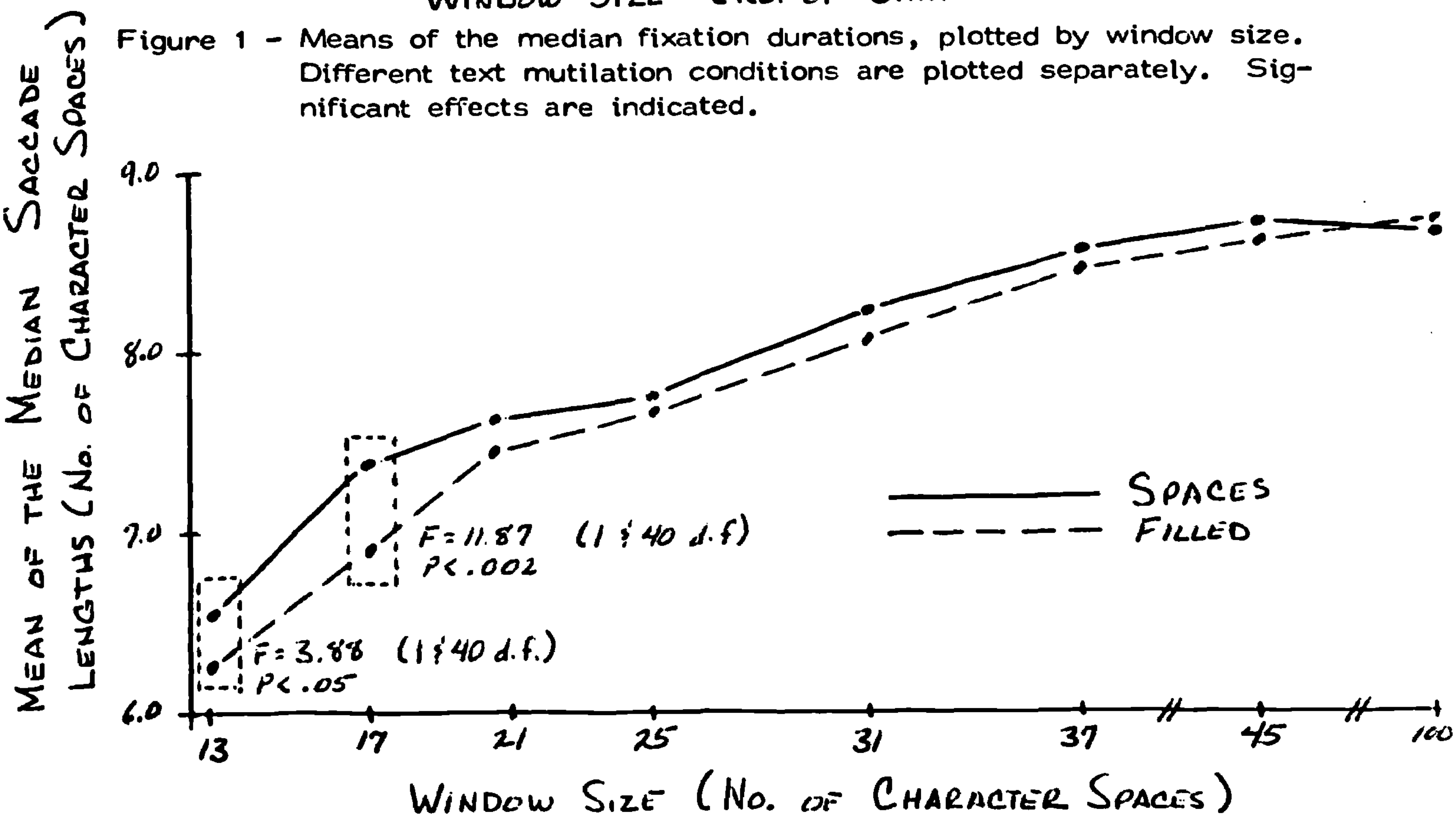

Figure 2 - Means of the median saccade lengths, plotted by window size. Space and filled conditions are plotted separately. Significant differences are indicated.

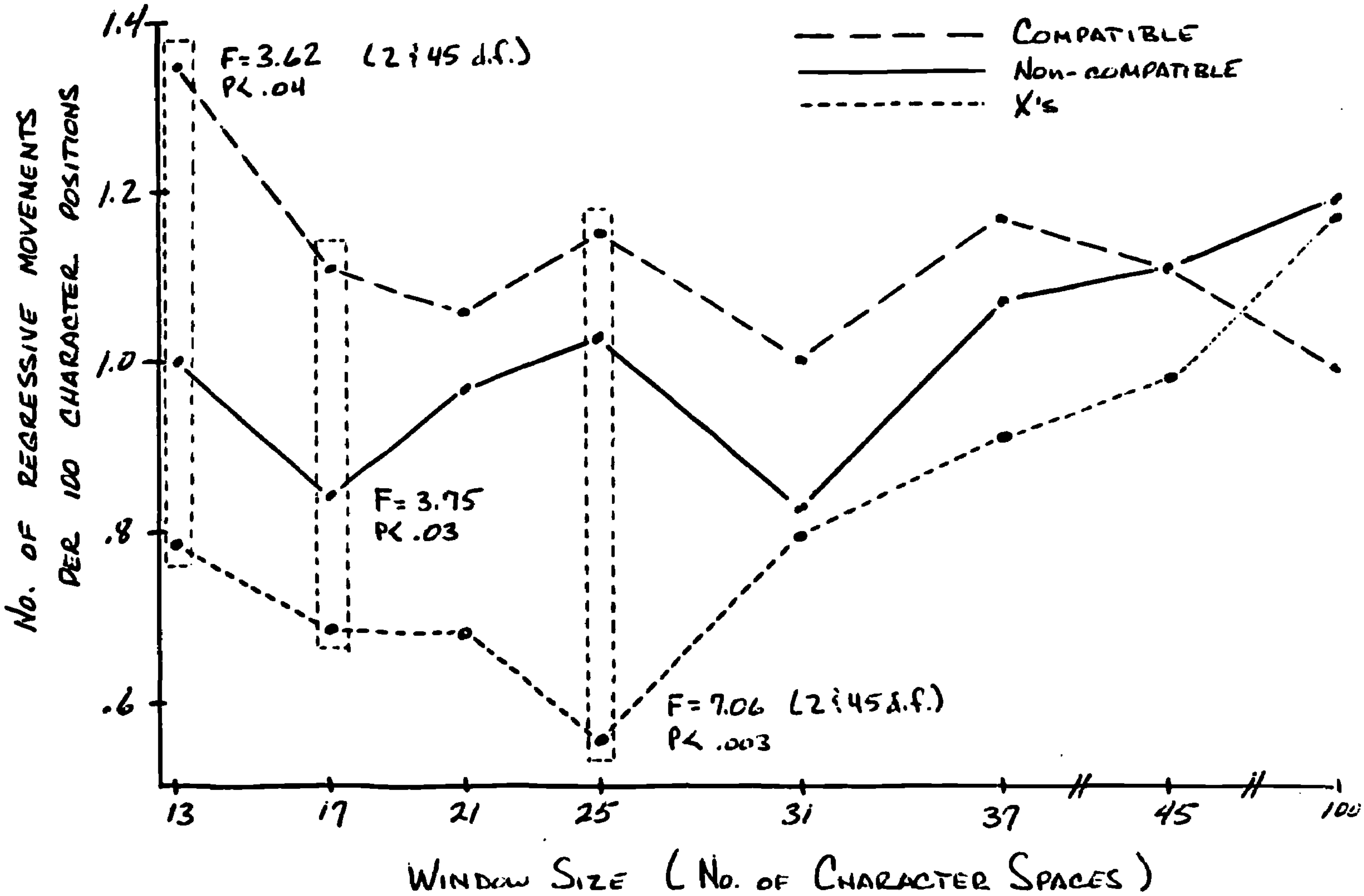

Figure 5 - Number of regressive movements per 100 character positions, plotted by window size. Different text mutilation conditions are plotted separately. Significant effects are indicated.

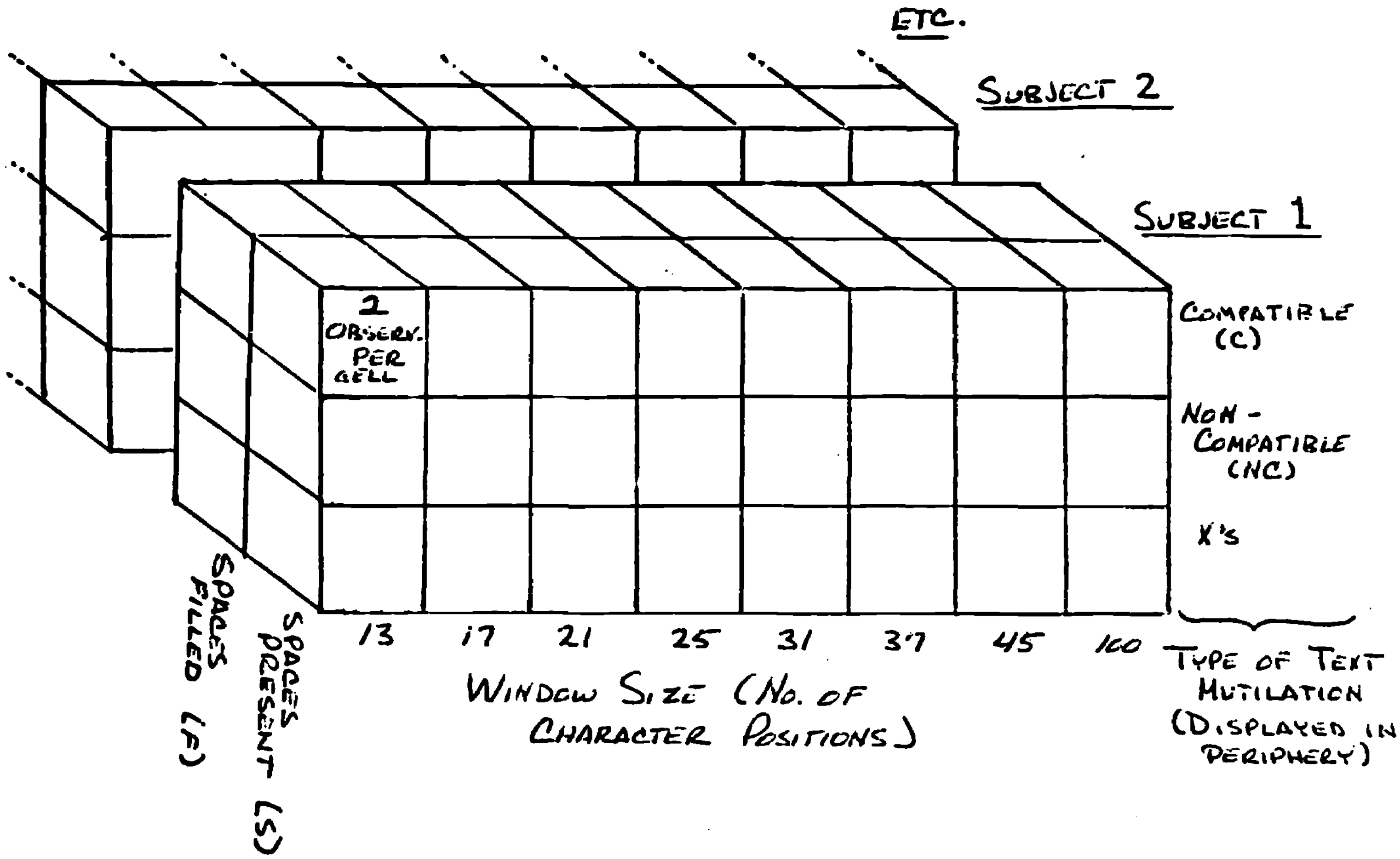

Figure 6 – Design of the experiment

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XXXXXXXX. XX XXXXXX, XXXX X XXXXXX XXXX X XXXXXXXX XXXXXXXXX XX XXXXXXXXXX

Figure 7 – Example of a window size of 17 with the xs version of mutilated text in the periphery. This display would be seen by the subject during a fixation if the eye tracking equipment registered a fixation on the letter e in the word the. The original display had 7 lines of text.