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Effects of screen presentation on text reading and revising

ANNIE PIOLAT, JEAN-YVES ROUSSEY AND OLIVIER THUNIN

Centre PsyCLE, EA 3273 Université de Provence, 29 avenue Robert-Schuman, 13621 Aix-en-Provence Cedex, France. email: piolat@up.univ-mrs.fr.

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Two studies using the methods of experimental psychology assessed the effects of two types of text presentation (page-by-page vs. scrolling) on participants' performance while reading and revising texts. Greater facilitative effects of the page-by-page presentation were observed in both tasks. The participants' reading task performance indicated that they built a better mental representation of the text as a whole and were better at locating relevant information and remembering the main ideas. Their revising task performance indicated a larger number of global corrections (which are the most difficult to make).

1. Introduction

The aim of the present experiments (one on text reading and the other on text revising) was to determine whether different screen dynamics influence the two-dimensional mental representation of the text built by users, and consequently, the actions they carry out during reading and revising. The two types of text presentation tested were implemented in two word-processing prototypes called *Page* and *Scroll.*

The two experiments reported here were aimed at showing that subjects performing a text-reading task and a text-revising task on a word processor do better work when the screen display maintains the spatial layout of the information by presenting the text in page format. Before describing the two studies, three major issues will be reviewed: (1) spatial encoding of information by readers, (2) the ability of users to verify and revise texts on a word processor and (3) the relationship between the type of text presentation and the mental load incurred by users.

2. Spatial encoding of information during reading

A number of findings are consistent with the idea that spatial encoding by readers involves building a mental representation of the location of text information. These locations include the position of letters in words, words in sentences and sentences or words in the text as a whole. Analysis of participants' eye movements while reading sentences on a computer screen or while locating linguistic units with the computer mouse, has shown that readers can reposition their gaze or relocate the mouse on a given word by making a single, very accurate regression or a single pointing movement (Kennedy & Murray, 1987; Pynte, Kennedy, Murray & Courrieu, 1988; Baccino &

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Pynte, 1991, 1994). These data provide support for the hypothesis that positional information is processed during reading. A number of studies have shown that after reading a text several pages long, readers are able to state where a word or group of words is located on the page, significantly more accurately than if they had pointed to a location by chance (Rothkopf, 1971; Christie & Just, 1976). During reading, then, information can be regarded as encoded in a two-dimensional space: the page of text. This space is represented in an external memory area where each piece of information is assigned an address in the form of (x, y) coordinates. This spatial representation is considered to be useful to readers during the comprehension phase. For example, it can help readers remove lexical or syntactic ambiguities, determine pronoun antecedents or improve subsequent recall of information in long texts (Lovelace & Southall, 1983). In other words, "The `where' may serve to recall the `what'" (Baccino & Pynte, 1994).

Obviously, these studies do not claim that all information in a text is encoded spatially. Readers more carefully memorize the location of information in places where additional cognitive processing is necessary (Baccino & Pynte, 1994). Several important points should be noted here. First, the frame of reference used to encode the location of information is still poorly understood. If it is true that the borders of a page (or of a window on a computer screen) can serve as reference points in a coordinate system, within which encoding operations are carried out, then perhaps readers also use other reference points such as the positions of words with respect to each other (Swanston, Wade & Day, 1987). Note also that in most studies, the readers' task consists of locating a piece of information on a given page and not within the text as a whole, which may cover several pages. Finally, with long texts (Christie & Just, 1976) or with a task requiring text location within unread whole document (Dillon, 1991), readers' knowledge of text content and organization probably contributes to building the mental representation of the spatial arrangement of the information.

Although the above studies deal with reading rather than writing, models describing the writing process emphasize the need to revise (and thus to read) the material as it is being written (Witte, 1985; Hayes, Flower, Schriver, Stratman & Carey, 1987; Esp&et & Piolat, 1990; Danman & Stainton, 1993; Plumb, Butterfield, Hacker & Dunlosky, 1994). Thus, the study of word-processor's use and how it affects writing should include an analysis of whether and in what ways the text presentation can disrupt, or on the contrary retain, the spatial layout of information a reader-writer spontaneously encodes, and in doing so, how it can affect text revising.

3. Revising text on a word processor

Not all authors who study word processing-as compared to composing with paper and pencil-and its effects on the quality of final text quality argue in favor of this computer tool (Bridwell, Johnson & Brehe, 1987; Piolat, 1991; Fitzgerald, 1992; Snyder, 1993). The various writing processes, including planning, revising and sentence generation (Bereiter & Scardamalia, 1987; Piolat & Roussey, 1992; Hayes, 1996) have indeed been shown to be disrupted in this production environment. Moreover, writers do not use it at all phases of the writing process, especially not during the first draft phase where ideas are generated and thoughts organized (Lutz, 1987; Severinson Eklundh & Sjiholm, 1991; Piolat, Isnard & Della Valle, 1993). Furthermore, the strategies devised for revising text with a word processor are quite different (Daiute, 1985; Hawisher, 1989; Piolat & Blaye, 199-1; Fitzgerald, 1992; Owston, Murphy & Wideman, 1992).

Writing with a word processor has been found to hinder revising in several ways. Error detection on the screen is slower and fewer errors are detected (Wilkinson & Robinshaw, 1987; Smith & Savory, 1989). Participants also take more time finding a piece of information on the screen (even if the text is bigger than one page) than on a printed copy (Hass & Hayes, 1986; Muter & Maurutto, 1991). They rarely use the word searching function, even though it would speed up their work and confine the revisions to the highlighted portion of text (Lutz, 1987). Although the absolute number of revisions is larger when revisions are made on a word processor, the corrections are usually surface corrections (letters, words, punctuation) and, unlike paper and pencil writing, they hardly ever affect deeper levels like text coherence and overall organization (Hass & Hayes, 1986; Barker, 1987; Lutz, 1987; Hass, 1989; Piolat, 1991; Piolat & Blaye, 1991; Fitzgerald, 1992; Snyder, 1993; Van Haalen & Bright, 1993).

Hansen and Haas (1988) pointed out a number of important features of computer systems and word-processing software that help account for some of the above findings. Features such as legibility, responsiveness, screen size and tangibility were found to affect reading and composition speed, as well as text quality and hence, writing effectiveness in general. These features may also determine writers' "sense of directness", "sense of engagement" and "sense of text" when using the computer. Poor legibility, e.g. may reduce error detection and reading speed (Gould, Alfaro, Finn, Haupt & Minuto, 1987; Mills & Weldon, 1987), just like a small screen, which requires frequent moves, may generate an attentional disruption (Neals & Darnell, 1984; Hansen & Haas, 1988; Dillon, Richardson & McKnight, 1990; De Bruijn, De Mul & Van Oostendorp, 1992). Moreover, the low tangibility of the screen display system ("the extent to which the state of the system appears to the user to be visible and modifiable via physical apparatus", Hansen & Hass, p. 1083, 1988) may affect users' ability to remember information locations. Usage of paper is thought to offer more tangibility because each piece of information occupies a single, fixed location on the page, providing users with visual cues (and even tactual ones: thickness of the read pile of paper and of the to-be-read pile) about the location of information with respect to the text as a whole (Duchnicky & Kolers, 1983; Hansen & Haas, 1988). In addition to participants' memory of locations, system responsiveness is thought to affect the rate at which users find information. Finally, the joint effects of several of these factors may prevent writers from getting an overall grasp of the text, thereby making coherence revisions more difficult. This limitation could be due to the small amount of visible text, which associated with low tangibility, reduces a user's knowledge of where information is located in the document. Slow responsiveness makes access to that information even more difficult (Severinson Eklundh, 1992; see Dillon, 1992 for a review).

All in all, compared to the paper-and-pencil production medium, the characteristics of the computer and word-processing software can make it difficult for writers to grasp the overall organization and flow of a text (referred to as "sense of text" by Hass and Hayes, 1986; "global perspective" by Severinson Eklundh, 1992).

To improve word-processing production via better text dynamics on the screen, engineers have designed several ways of presenting and moving through text. We shall now compare some of these operating modes.

4. Screen dynamics

A number of features can help distinguishing between Page and Scroll mode. The most relevant are listed below.

The way a text is presented on a computer screen and how users can reach various passages in the text is referred to as screen dynamics (Gray, Bradford Barber & Shasha, 1991; Mills & Weldon, 1986). Although several types of screen dynamics are available in word processing programs, they may not maintain the spatial layout of the text as in reading or writing on paper. The most commonly used type of screen presentation is scrolling. In a scrolling environment, users have "scroll arrows" to make text move through a display window towards the beginning or the end of the document. To increase tangibility, the entire text is represented by a "scroll bar" which contains a "scroll box" to indicate the position (in the text) of the portion of text currently displayed on the screen. Because the scroll bar represents the whole document, regardless of its absolute length, the position indicated by the scroll box is relative. The scroll bar enables users to move quickly through portions of text. However, it only provides an approximate idea of the location of what is currently displayed on the screen ("near the beginning", "somewhere around the middle", "near the end", etc.).

The page number ("x" or "x/y"), which is the page number once the document is printed on paper, is another indicator for locating the displayed text. However, unless a user has a large screen (A4 format), the display window is smaller than a standard printed page. Although the page number gives a more accurate indication of the location of the displayed part of the text than the scroll box, once the page is reached (by one of a number of ways including the command "Go to page x") the portion of text that ends up getting displayed is not necessarily exactly the one the user was hoping to find.

The scrolling system with its various positional cues does not provide writers with enough "tangible" data about the location of information that is not currently on the screen. Each time the scroll arrows are used, or even the scroll bar, the spatial layout is disrupted, making it difficult for writers to build a two-dimensional representation of the entire set of information being written or read. Moreover, even when the scroll box is used, scrolling through the text to find a particular piece of information can be slow, especially when the desired text passage is far from the current location. This postpones the time when users reach the required location and may necessitate several adjustments of the screen, producing a working memory overload. Taken together, the slowness and imprecision of moves within the text, the disrupted spatial layout, and the limited view of the text due to screen size, appear to make it difficult for writers to get a "sense of the text" and to work on text coherence and overall structure.

Another way of moving through the text is to use the page-up and page-down keys on the keyboard or to click on the scroll bar above or below the scroll box to shift the text by a span of lines equal to the screen size. This gives users the impression that they are reading on pages, and it is faster than simple scrolling. This "paging" method is preferred over line-by-line scrolling and gives rise to better performance on sorting tasks (Schwarz, Beldie & Pastoor, 1983). But it is only when a reader-writer does little proofreading and correcting that he/she can go back and forth between pages in this manner and still benefit from some "constants". When page-by-page moving is combined with scrolling, users never find the same lines at the top of the screen and, therefore, cannot rely on fixed spatial cues for locating information in a long text.

Finally, the so-called "page" mode provided by word processors only seems to be useful for verifying the paging and paragraph layout once the writing phase has been completed. This mode is slower than the normal mode and thus offers poorer responsiveness. Besides, the pages are displayed on the screen as they will appear in print, and users must rely on the scroll arrows to see an entire page (unless the screen is large). As with "paging", the only indications about where in the text the current display is located are given by the scroll bar and the page number. Hansen and Haas (1988) showed that individuals reading on the screen compared to reading on paper-even with the paging type of display-have a less accurate idea about the vertical position of the words in the text, even though they need to locate information if for no other reason than to evaluate text coherence or make changes in the overall structure.

In an attempt to maintain the spatial layout of texts, Severinson Eklundh and Sjilhom (1991) developed a prototype called "Paper" that displays text in as stationary a manner as possible, while still improving system responsiveness. In this system, users write in separate windows which represent sheets of paper and can be accessed as desired on the screen. Because each piece of information in the text can be associated with a given window, this display system partially reproduces the tangibility features of writing on paper. The possibility of moving directly from one page to another improves responsiveness, especially during access to distant parts of the text.

This type or presentation has one major shortcoming, which becomes evident when text is being inserted. Whenever there is not enough space to make a large addition to the text, the current window is automatically divided into two windows. After a number of such insertions, the text is broken down into many unequally filled windows and looks "messy". Severinson Eklundh *et al.* noted that after several insertions, users often run the "compress" command, which deletes useless space in the windows and gives the text the neat and finished look appreciated by writers.

Severinson Eklundh and Sjiholm (1991) did not conduct any experimental studies to determine whether Paper actually improves the writing process. However, their case studies showed that the system gives writers a good overview of the text, and that the pages displayed on a screen may serve as a memory aid for locating information in the text. In the same vein, Tombaugh, Lickorish and Wright (1987) showed that information in a text displayed in several windows is found faster than when the text is presented in only one window, although the word-processing prototype used by these authors was very different from Paper. In the Tombaugh *et al.* system, each window corresponded to a thematic section of the text, and scroll arrows were included, so that the amount of text per theme could exceed the window size. This prototype allowed users to spatially locate themes without requiring the use of fixed spatial cues to point to smaller linguistic units.

5. Experiment 1: Spatial encoding of information during reading

The critical hypothesis in Experiment 1 is that reading performance would vary with text presentation: Page vs. Scroll mode. The following levels are considered here.

(1) Level *of* participants' involvement in the task. Participants should be more active during the text comprehension phase. This should occur because forward and backward moves are easier to make in the Page condition.

(2) Level *of* mental representation *of* the spatial layout. Participants should more accurately locate items in the text. This is possible because Page presentation facilitates spatial encoding of information during reading.

(3) Level *of* processing saliently located information (i.e. information at the top or bottom of a page). This information should be recalled better than sentences in the middle of the text.

(4) Level *of* locating information in the text. Information in salient areas should also be located better when the spatial cues available during text reading are made available later on when information has to be located. This should happen because sentences in Page presentation are positioned in a paginated space.

(5) Level *of* text comprehension. Participants' feeling for the "macrostructure" (i.e. the most important information; Van Dijk & Kintsch, 1983) should be better because of the dynamic features of Page presentation.

(6) Level *of* detail processing. More details should be recalled as details are better linked to the text macrostructure in Page presentation.

5.1. METHOD

5.1.1. Materials

Text presentation. The two types of screen presentation (see Appendix 1; Figures 1 & 2) are (1) a conventional scrolling technique for reaching new or old information in a text and (2) a page-by-page display that immediately showed the entire new or old page. The two corresponding screen management prototypes, Scroll and Page, were written in HyperTalk. The size of the display window was identical in the two modes, as was the amount of text on the screen. The display window showed 18 lines of approximately 50 characters (range: 43-53). The text was 72 lines long and was left justified. A 12-point character font was used with 18-point spacing between the lines. Note that the window was purposely made small so that a short document could be used (574 words). This was designed to keep the processing load low.

Reading with the Page prototype took place as follows. On the right of the text window, users had four numbered icons corresponding to the four pages of the text. The highlighted icon indicated which page was currently on the screen. A different page could be displayed by simply clicking the mouse on one of the other icons. This allowed participants to go directly and quickly from page 1 to page 4, e.g. without having to scroll through the middle of the text. With the highlighted icon, then, the position of the visible page relative to whole text was always available to participants. This display system should allow users to mentally organize all information in the text (both visible and not visible) into ordered pages.

The Scroll prototype reproduced the type of presentation commonly proposed in word processors, where users have two arrows which can be clicked to move text material upwards or downwards. However, the scroll bar did not have a scroll box indicating the current position within the whole text. The idea here was to make the two types of presentation as different as possible. In the case of Page, information in the icons was designed to lead users to break down the text into ordered sections or "pages". With the Scroll system, the breakdown was always temporary because the text was continuously transformed by the effects of scrolling. Users had no indication of the approximate location of the information being read unless they were at the beginning of the text where the title was shown, or at the end where the word END was displayed.

For both systems, participants' moves throughout the text were tracked and stored in a file called the "navigation file". Every time a move was made, whether via the page icons or the scroll arrows, the program read the new line number displayed at the top of the screen and stored it in the navigation file. This file was used later to count the number of times participants backtracked.

Sentence locating task. This task was designed to determine how participants build a mental representation of the spatial layout of text information as they read. Participants were asked to indicate where key sentences were located in the previously read text. The space occupied by the text was depicted by a box, 3 cm wide and 15.5 cm long, showing 72 empty lines (corresponding to the 72 lines of text).

Two ways of pointing to sentence locations were set up in order to see whether readers spatially encode information in the text by segmenting it into pages (as they do when reading in print), one called the *page-break system* and one called the *no-page-break* system (see Appendix 2). The response box (which represented the text on the screen) was of the same size in the two systems. In the page-break system, the response box was divided into four sections of 18 lines each separated by a heavy solid line. The divisions were supposed to help readers activate some of the spatial cues provided by the upper and lower limits of the four pages defined by the Page prototype during reading. In the no-page-break system, the heavy lines were not shown so as to avoid facilitating a "page-based" representation of the text.

Verbal materials. The text chosen for the study was that used by Ehrlich (1994) in a number of experiments on text comprehension ("The Sanding Over of the Mont Saint-Michel"). It is a 427-word expository text about the Mont Saint-Michel, one of the most prestigious abbeys in France, perched on a small island in Brittany. The text describes how tides are sanding over the abbey, and discusses some of the potential ways of preserving the site. The hierarchical structure of the information in this text is well known. The constituents of the text's macrostructure (the information that would be included in a summary) and the details were identified. However, in order to fill up four screen pages, the text was lengthened to 574 words (without changing its semantic structure) by minimal paraphrasing and by writing out the numbers as full words.

Eight sentences were chosen for the locating task that would follow the reading. Each selected sentence had to meet two criteria: (a) Any potential effect of the importance of the information that might change readers' ability to remember and locate the sentences were avoided. So, four of the sentences contained "macropropositions" (information at the highest level in the importance hierarchy) and four contained information of minor importance. (b) In order to determine whether the readers' ability to spatially encode text information relies on salient spatial cues like the beginning or the end of a page, four of the sentences were near page breaks (hereafter called boundary-zone sentences), and the other four were located in the middle of the page (hereafter called central-zone sentences).

5.1.2. Procedure

Training. Fifty-four second-year undergraduate psychology students participated in the experiment. None of them used a computer on a regular basis.

Before beginning the experiment, participants were taught how to use the mouse by clicking on a series of 10 buttons in various locations on the screen. Then they were shown how to navigate through a fictitious text composed of a sequence of meaningless letters, either using the page icons or the scroll arrows, depending on the experimental condition to which they would be assigned.

Reading task. Before reading the experimental text, participants were told that they would have to read a text and "take the time to understand it and be able to answer questions about it later". These are conventional instructions for text comprehension and recall tasks (Ehrlich, 1994). There was no time limit on the reading, and participants were free to use the page icons or scroll arrows as desired. Backtracking was allowed.

Sentence locating task. After reading the text, participants had to locate each of the eight test sentences, either in the response box that had page breaks, or in the one that did not (Lovelace & Southall, 1983). The test sentences were displayed one by one in a predefined random order in a box on the left-hand side of the screen. The participants were told to use the mouse to indicate what they thought was the location of the sentences in the text, by clicking on a line in the response box (with or without page breaks) located on the right-hand side of the screen. A file called the "pointing file" was used to store the coordinates of the screen pixel where participants pointed for each sentence. The top of the response box was labelled "Beginning of text", and the bottom, "End of text".

Participants began by reading the task instructions that were displayed on the screen, including a part about "locating the sentence as accurately as possible". Instructions remained on the screen throughout the task. In addition, before starting, the experimenter insisted that participants try to find the exact location of each sentence "right down to the very line" and to "think carefully before clicking because answers could not be changed".

The test sentence box was of the same width as the Page and Scroll reading windows. The sentences were displayed in the same layout as in the text (i.e. the sentence began at the same distance from the left margin of the box and the paragraphing was identical), so that participants would not be disturbed by changes in the spatial format of the sentences. Once a subject had responded, the next sentence was written over the first in the test sentence box, and the response box no longer showed any signs of the previously chosen location.

Summarizing task. After having located the sentences, the participants had to write a summary of the text on paper. Following Van Dijk and Kintsch (1983), the instructions (on the computer screen) reminded them not to "forget any important ideas in the text".

Because we only wanted to compare the quality of the summaries produced by readers who had read the text using the Page and Scroll systems, participants who had located sentences using the no-page-break response system were the only ones to write a summary.

The 54 participants took about 45 min to perform the various tasks in this experiment (training, reading, sentence locating, summarizing).

5.1.3. Dependent variables

Reading time and number of backtracking sequences. The time taken to read the text was recorded for each subject. The number of backtracking sequences produced by each subject during reading was calculated as follows. Backtracking was defined as any operation or sequence of operations carried out by readers to display a portion of text (whether a line, several lines or a page) that preceded their current reading location. A sequence consisted of all backward moves made in succession before going forward to the original location in the text. The variable used as an index of reader mobility was the total number of backtracking sequences made during the entire reading task. The number of lines moved on the screen on each operation could not be used because this would have given an unfair advantage to the Page readers (1 backtracking operation = 18 lines moved). The number of individual backward moves could not be used either, because Scroll readers could move one line at a time until the desired area was reached, and thus generate a large number of moves. Combining the operations into "sequences" thus seemed to be a good solution for assessing reader mobility.

Pointing accuracy. Pointing accuracy was measured by taking the mean difference (in number of lines) between the locations chosen in the response box and the real locations of the sentences in the text. To calculate this difference, the mean vertical coordinate of the eight test sentences (a sentence could occupy more than one line) was expressed in a number of lines from the beginning of the text. When a reader pointed with the mouse to the estimated location of a sentence, the program read the vertical coordinate of that location in pixels, relative to the upper edge of the box. Each line of text took six pixels. This coordinate was then corrected so that it could be compared with the location of the sentence in the text. The more accurate the response, the smaller this difference (in number of lines).

Summary grade. The 26 summaries were typed and numbered, and then piled up in random order to be graded by four judges. Based on the macropropositional analysis of the text (see Van Dijk & Kintsch, 1983; Ehrlich, 1994), the ten sentences expressing the main ideas in the text and the 15 sentences stating less important information (details) were listed.

Two of the judges graded the summaries for the important ideas and the other two judges worked on the details spontaneously provided by the participants. The grading was carried out in two steps. First, judges worked individually. Every time a portion of text was found that was very close in meaning (a paraphrase) to one of the ideas on the list, it was circled and numbered. The summary was graded by giving one point for each idea found (making a total score of up to 10 for important ideas and 15 for details). Then, the two judges worked together and came to an agreement on the ideas identified, their numbering and the overall grade assigned to each summary. Thus, the final grade (important ideas, details) assigned to each summary were the result of this agreement.

5.2. RESULTS

5.2.1. Experimental factors

The experimental factors manipulated in this experiment were text presentation ($D2$ = {Page, Scroll{}), response system ($R2$ = {page-break, no-page-break}) and sentence location (Z_2 = {boundary zone, central zone}). Depending on the variable, either Fisher's test or analyses of variance were used.

5.2.2. Reading time and number of backtracking sequences

The mean time taken by participants to read the text did not differ significantly between Page and Scroll (Page = 459 s; Scroll = 442 s; $F < 1$), nor did the number of backtracking sequences, even though readers tended to produce more backtracking sequences with Page (1.61) than with Scroll (1.17; $F(1, 70) = 2.23$, $p < 0.14$).

5.2.3. Pointing accuracy

In line with Prediction 2, Page allowed participants to locate test sentences with a significantly higher degree of accuracy than Scroll (mean distance in lines: 7.68 vs. 10.56; $F(1, 68) = 15.92$, $p < 0.001$). However, this difference was no longer significant when the no-page-break respone system was used (mean distance in lines: 9.08 vs. 9.32 lines, see Table 1).

The text presentation by response system interaction turned out to be significant ($F(1, 68) = 13.36$, $p < 0.001$). The page-break system (which reproduced the spatial cues that marked the pages defined in Page) resulted in an improvement in locating accuracy only when the text had been read with Page (mean distance in lines: 6.28 vs 9.08; $F(1, 68) = 7.5$, $p < 0.01$).

With Scroll, locating accuracy was significantly poorer in the page-break system, where there were spatial cues to which the readers did not have access during the reading task (mean distance in lines: 11.80 vs. 9.32; $F(1, 68) = 5.91$, $p < 0.05$).

5.2.4. Pointing accuracy by zone

As indicated by the interaction between presentation and test sentence zone ($F(1, 68) = 2.55$, $p = 0.11$), it was only with Page that the sentences in the boundary zones were located more accurately than those in the central zones (6.95 vs. 8.40; $F(1, 68) = 2.44$, $p = 0.12$, see Table 2). This breakdown into simple effects makes the interaction clearer. Prediction 3 proved to be true.

Only for the Page system did the sentences in the boundary and central zones tend to be located more accurately (Table 3) with the page-break response system (boundary: 5.33 vs. 8.57; $F(1, 34) = 7.16$, $p = 0.011$; central: 7.22 vs. 9.58; $F(1, 34) = 3.88$, $p = 0.057$). When the response system had page breaks, the sentences in the boundary zones were

TABLE 1

Mean difference (in number of lines) between the chosen location and the actual location of test sentences, as a function of text presentation (Page vs. Scroll) and response system (page-break vs. no-page break)

	Page	Scroll
Page-break response system	6.28	11.8
No-page-break response system	9.08	9.32

TABLE 2
Mean distance (in number of lines) between the actual location and the chosen location of the sentences, by text presentation (Page vs. Scroll) and sentence location (boundary zone vs. central zone)

	Page	Scroll
Boundary zone	6.95	10.93
Central zone	8.40	10.28

TABLE 3
Mean distance (in number of lines) between the actual location of test sentences and the location chosen by Page readers, as a function of response system (page-break vs. no-page-break) and test sentence zone (boundary zone vs. central zone)

	Page-break response system	No-page-break response system
Boundary zone	5.33	8.57
Central zone	7.22	9.58

located more accurately than those in the central zones (5.33 vs. 7.22; $F(1, 34) = 3.30$, $p = 0.078$), which is consistent with our hypothesis that locating would be facilitated.

5.2.5. Summary grade

For the most important information in the text, the summary grades given by the judges were not very high. The summaries were incomplete and did not contain very much of the important information. In line with Prediction 5, the mean grade for the Page summaries was higher than for the Scroll summaries. However, this difference was not statistically significant (2.61 vs. 1.83; $F(1, 34) = 1.865$; $p = 0.1811$).

Readers included very few details in their summaries, but they did so significantly more often in the Page condition than in the Scroll condition, which validates Prediction 6 (3.61 vs. 5.33; $F(1, 34) = 3.907$; $p = 0.0562$).

6. Experiment 2: Text revising

When revising with the Page system compared to Scroll system, writers should be able to (a) build a better representation of the text and be more efficient at diagnosing the problems it contains and (b) more effectively correct coherence errors.

Three predictions were tested. (1) With Page, writers should have a better overall representation of the text and of any coherence problems it contains. Thus, in the course of the revising task, they should do more backtracking and moving around in the text than those working in Scroll. (2) Page writers should verify and correct the text for coherence more frequently than writers working in Scroll. (3) Page writers should benefit from the navigation ease offered by this presentation system and correct coherence errors more often by transferring portions of text to places which were far away from their original location, an operation which requires processing large spans of text.

6.1. METHOD

6.1.1. Materials

Text presentation and text processing. The text presentation types of Experiment 1 were used again (Page and Scroll). To enable writers to revise their text, minimal keyboard editing and insertion functions were added to the Page and Scroll prototypes (see Appendix 3). The addition of these word-processing functions did not pose any particular problems for the Scroll environment. For Page, however, the text had to be immediately reformatted after each correction and any variations in text size had to be incorporated so as to ensure maximal stability of the page-based format.

The Page prototype of Experiment 2 now had five page icons instead of four as in Experiment 1. This gave writers the freedom to revise the text by adding a large amount of text if necessary. Between 10 and 45 characters could be added to a paragraph without changing the number of lines, and thus the overall layout of the page. When inserted quantities were too large, text following an insertion point was shifted downwards and the paging was changed accordingly. Thus, Page included a module that managed text display in accordance with the transformations made. This module always highlighted the current page icon (even after a paging change).

When writers wanted to select text portions that spanned two pages, texts could be scrolled up or down. This was done in the usual manner by clicking at the beginning of the desired text portion and dragging the mouse until the cursor reached the top or bottom edge of the window. This caused the document to move and the previous or next page to be displayed, as in a conventional word processor. Whenever writers cut, deleted or removed the highlighting from the portion of text overlapping the page break, the program immediately reformatted the current page.

Editing functions and the "word processor". As in Experiment 1, none of the participants in Experiment 2 were regular users of a computer. A "minimal" word processor was necessary so that they could become accustomed to the task environment. The operations they carried out to revise on the screen were recorded. The limited number of editing functions facilitated programming and data analyses.

In addition to accepting inserted text typed on the keyboard, this "mini-word processor", written in HyperTalk, offered four editing functions (select, cut, paste, delete) which made common text editing operations possible (delete, add, replace, move between 1 and *n* characters). Highlighting was achieved by clicking on the mouse at the beginning of the to-be-selected text and dragging the cursor across the targeted words. The other functions could be activated by clicking on the desired icon (scissors, glue or eraser). The delete key on the keyboard (DEL) and the keyboard functions and arrows were inactivated. The program did not include the "Undo" function and writers had to delete highlighted text before pasting or typing new text in place of it.

Recording writers' actions. The word processor included a subroutine that recorded the different actions performed by writers on-line. The "navigation" file (described above in Experiment 1) kept track of the writers' moves in the text. A file called the "revision file" was used to store the corrections made to the text. Each time a writer carried out an operation (cut, paste, delete, insert from keyboard), the program used the revision file to copy the paragraph (or paragraphs if more than one) in which the correction was made. The text portions (cut, pasted, deleted or inserted) were stored between two predefined header characters indicating which editing icon was used to make the change. The revision file thus contained the ordered sequence of modified paragraphs so that the nature of the modifications made by writers could be examined.

Verbal material. The text material from Experiment 1 was used again here ("The Sanding Over of the Mont Saint-Michel"). Various mistakes had been purposely introduced. A preliminary test on paper taken by 28 first-year psychology students had shown that the mistakes were easy to detect and correct. The experimental text covered four pages. The size of the characters, the spacing and the justification were similar to those of Experiment 1.

The mistakes introduced in the text were designed to force the writers to process several text levels (i.e. surface, cohesion, coherence). They were not limited to local transformations (i.e. within-word, within-phrase or between-phrase) and required corrections across pages. In other words, the errors were designed in such a way that writers had to go from one screen page to the next and revise over large spans of text.

The errors were constructed by combining two factors: the structural level of the text (surface, cohesion, coherence) and the operation needed to correct the error (move or replace). This made six error types, each of which occurred twice, so that the text contained a total of 12 errors (see Table 4).

By varying the structural level of the errors, we were able to force the writers to consider spans of text of various lengths in order to diagnose the problems. The errors were chosen among the broad range of errors frequently made in students' written work. There was a sufficiently wide variety to prevent the revising task from being too easy. The errors had to meet the following criteria. (a) Surface errors could not change the meaning of the text. To be detected and corrected, writers need only do a very local kind of processing (tapping their knowledge of spelling or grammar at the phrase level) and there was no need to build a global representation of the text. (b) Cohesion errors could only affect the relationships between the constituents of a sentence or adjacent sentences and therefore had to transform the microstructure of the text. To be corrected, they only required grasping the meaning of the concerned portion of text and here again, did not necessitate an overall representation of the meaning of the text as a whole. Correction required a relatively "local" approach (same screen page). (c) Coherence errors modified the meaning of the text. To be corrected, these errors required writers to have already built-or have attempted to build-a coherent representation of text content which linked different blocks of information together. The errors were chosen in such a way that writers could not simultaneously display all passages where coherence was being assessed.

TABLE 4

Types of mistakes introduced in the text of Experiment 2, as a function of type of operation needed for correction (move, replace) and structural level affected by the error (surface, cohesion, coherence)

Move
Surface
Move a letter in word
Move an article in a sentence
Cohesion
Move a pronoun between two statements
Reverse the order of two adjacent sentences
Coherence (1), (2)
Move a connective 18 lines away
Move a sentence 28 lines away
Replace
Surface
Replace a letter in a word
Replace an article in a sentence
Cohesion
Replace a pronoun in a sentence
Change a verb tense (tense agreement between two adjacent sentences)
Coherence (1)
Replace a connective
Delete the negation in a sentence

(1) Errors which required handling a span of text extending over two screen pages in order to be detected.

(2) Errors which required verifying a span of text extending over two screen pages in order to be corrected.

The move and replace operations were chosen so that the writers would be forced to act upon different spans of text in order to make the appropriate modifications. Replacing consisted of deleting a portion of text (using the delete function or possibly the cut function) and reinserting text from the keyboard (except for the error "Delete the negation in a sentence", where only deletion was required). The span of text that had to be verified to carry out this type of operation was small, regardless of the structural level involved. Thus, once the error was detected and a solution found, writers did not have to move to make the correction. Moving consisted of deleting a portion of text (using the cut function) and reinserting it in another place in the text (paste function). To achieve this type of revising, writers had to verify two "locations" in the text: one where the portion of text had to be deleted and another where it had to be reinserted. The distance between these two locations depended on the structural level affected by the error.

Table 4 above summarizes the format of the information (within-page vs. between-page) that writers had to display in order to detect and correct the different types of errors.

6.1.2. Procedure

Participants (n = 26; second-year undergraduate psychology students who were unfamiliar with word processing) were randomly assigned to the two conditions. They took about 60 min to carry out the two tasks in this experiment (training, text revising).

Training. The training phase started in the same manner as in Experiment 1 (i.e. learning how to use the mouse and read a document in the Page or Scroll environment). Then participants were taught the editing functions. The goal of the training phase was to make sure that all writers had an equivalent level of proficiency in handling the editing operations that they would have to use during the revising task. The training exercises dealt with a variety of text units (ranging from a letter to a paragraph) in order to show writers that changes could be made at every structural level.

Each writer did 14 computer-driven training exercises. All exercises were presented on the screen in the same format. On the left of the screen, the method for performing the various actions was displayed (type, highlight, delete, etc.) along with the statement of the exercise to which the method was to be applied. The exercises were done on a short text presented on the right-hand side of the screen, below which the necessary buttons were shown. The exercises involved inserting from the keyboard, highlighting with the mouse (a word, a letter, a sentence and a paragraph), highlighting then deleting (a word, a letter, etc.) with the delete icon, highlighting then moving (a word, a letter, etc.) using the cut and paste icons, and finally, moving a portion of text from one end of the document to the other, either using the scroll arrows or the page icons.

Revising task. After the training phase, the revising instructions appeared on the screen and informed participants that a text containing "certain things that weren't right and that sometimes made the text incoherent" would be displayed. The instructions also stated that the text contained "letters, words or blocks of information (several words, sentences, etc.) that were superfluous, missing or misplaced". Participants were supposed to read the whole text first and then try to improve it as much as possible using the just-learned techniques. The instructions emphasized the coherence of the text (blocks of information, sentences, etc.) and not only its surface structure (letters, words, etc.). The required initial reading was supposed to familiarize participants with the overall meaning of the text before they started making corrections and promote the potential discovery of coherence revisions.

Participants corrected the text under the Page or Scroll condition. They were free to use the cut, paste, delete and insert-from-keyboard functions. They could not take notes on paper or print the text.

The screen also showed a button labeled "I am done correcting". Clicking on it caused the appearance of the question "Are you sure you have finished correcting the text?" along with "Yes" and "No" buttons for responding. The experimenter encouraged participants to proofread the entire text before answering "Yes" and to make sure that no incoherence remained. Thus, writers read the text at least three times: one initial reading to get acquainted with the text, at least one pass through to make the corrections and at least one required proofreading at the end, potentially accompanied by corrections if a participant detected any more errors.

6.1.3. Dependent variables

Revising time and number of regressions. The time taken to carry out the task and the number of backtracking sequences were calculated as in Experiment 1.

Scoring the corrections. Simply scoring the errors as "corrected" (vs. "not-corrected") when the error was corrected exactly as predicted turned out to be inadequate because writers found many unexpected solutions to solve the problems and improve the text. So, in order to take into account effective but unexpected corrections, errors processed at the required structural level (surface, cohesion or coherence) were counted as corrected. For example, suppose a writer had to make a coherence revision and settled for substituting *"sont"* (are) for *"serait"* (would be) in the misplaced sentence *"Après le reflux de la marée, deux ou trois pour cent de ce sable sont ainsi déposés autour du Mont Saint-Michel"* (After the ebb-tide, two or three percent of the sand would thus be deposited around the Mont Saint-Michel). This transformation only changed within-sentence cohesion, so it was scored as not-corrected. Now the error would have been scored as corrected had the writer moved the sentence (even to the wrong place) or deleted it. This type of transformation was indeed indicative of this writer's more or less successful attempt to improve the overall coherence of the text.

A second, more stringent type of scoring was applied to the six errors that required to move. To be scored as corrected, a move not only had to involve the structural level of the error, but also had to be achieved using the predicted move operation.

6.2. RESULTS

6.2.1. Experimental factors

The experimental factors manipulated in this experiment were (1) text presentation ($D2$ = {Page, Scroll}), structural level affected by the error ($L3$ = {surface, cohesion, coherence}) and correction operation ($O2$ = {move, replace}).

Revising time and number of backtracking sequences. The mean time taken by writers to modify the text with Page and Scroll did not differ significantly (Page = 1496 sec.; Scroll = 1731 s; $F(1, 24) = 1.13$). In line with Prediction 1, writers using Page did more backtracking than those using Scroll (7.85 vs. 4.07; $F(1, 24) = 6.25$, $p < 0.02$).

Error correction. Writers did not make significantly different surface or cohesion improvements under the Page and Scroll conditions. On the other hand, in line with

TABLE 5

Mean error–correction percent for surface, cohesion and coherence errors under the Page and Scroll conditions

	Page	Scroll	Fisher's test (one-sided)
Surface	76.92	84.61	$p > 0.22$
Cohesion	86.54	94.23	$p > 0.15$
Coherence	50.00	30.77	$p < 0.04$

TABLE 6
Mean error–correction percent and p-values on Fisher's one-sided test for revision of surface, cohesion and coherence errors using the predicted move operation, as a function of presentation (Page or Scroll)

	Page	Scroll	Fisher's test (one-sided)
Surface	65.38	50.00	$p > 0.20$
Cohesion	53.85	53.85	$p > 0.60$
Coherence	34.62	11.54	$p < 0.05$

Prediction 2, the number of coherence revisions was significantly higher with Page than with Scroll.

With the more stringent scoring criterion used on the six move errors (structural level *and* predicted move operation), only the coherence error correction rate differed significantly across text presentations. It was significantly higher when the text was presented in page format (see Tables 5 and 6).

7. Discussion

7.1. INTERPRETATION OF THE RESULTS OF EXPERIMENT 1

Experiment 1 was aimed at determining whether (1) Page presentation prompted readers to be more mobile in order to reread certain passages and (2) Page presentation allowed readers to build a spatial representation that was more accurate than Scroll, by providing them with spatial cues (page boundaries and numbers) that could be retained.

Mobility within the text. As predicted, readers informed that they would have to answer questions about the text which tended to move around more when using Page for familiarization than when using Scroll. Note that their greater mobility did not affect their overall reading time.

Spatial representation of the text. Data from the sentence locating task showed that readers in the Page environment located sentences better than those in the Scroll environment. The page breaks (i.e. the boundary zones) were encoded and became part of the spatial representation of the text, as indicated by the fact that analogous boundary marks in the response system only increased locating accuracy when the text had been read with Page. Thus, the more tangible indicators offered by Page, and the possibility of relying on fixed locations relative to the spatial cues provided by the page format, allowed Page readers to build a more accurate spatial representation of the text than the Scroll readers.

Contrary to predictions, when the pointing system had no page breaks, the two types of text presentation did not lead to different locating accuracies. This lack of a difference may be due to the fact that the salience of the pages was so strong that it made it difficult to use a response system that did not reproduce the breakdown into pages.

This brings up two points that became obvious during Experiment 1. First, at the end of the task in the Page/no-page-breaks condition, most readers said that the sentence locating task was "difficult" because the response box "was empty and the page boundaries were not marked". Second, the hand gestures of these same participants as they carried out the sentence locating task suggested that they were attempting to gauge the location of sentences by marking off the four pages with their thumb and index finger.

According to our hypotheses, the response-system factor should not have affected locating accuracy for readers who used Scroll. However, contrary to predictions for these readers, the page-break pointing system significantly decreased locating accuracy compared to the no-page-break system. This means that the presence of boundary marks in the response box for readers who did not have such marks during reading disrupted sentence locating. The readers in the Scroll condition may have had a tendency to define "pages", on which they grouped information judged to be related to the same theme. In other words, they confused semantic proximity and spatial proximity.

Finally, perhaps, Scroll readers built a representation of the text structure that was based on sequential rather than spatial cues (e.g. located before, located after such and such a piece of information). This would follow from the continuous text presentation to which they were exposed, which was indeed sequential (the text moved by as readers remained in the same place) instead of spatial (readers moved through a stationary text bounded by delineated spaces). They may have attempted to adapt to the reading conditions and construct different cues than those used to access information in a book. These cues could be studied by proposing Scroll readers other systems for locating sentences in a text.

Representation of the text's information hierarchy. As expected, readers in the Page condition tended to recall the main ideas and details of the text better than Scroll readers. However, the difference in the summary grades attributed by the judges was only significant for details. The poor grades indicate that the readers wrote very short summaries, recalling an average of two out of ten main ideas and four out of fifteen details.

These results should be confirmed by further experimentation. However, they suggest that readers construct a better mental representation of information in a text when reading in page format. The spatial characteristics of a text may help participants better understand and retain its content.

7.2. INTERPRETATION OF THE RESULTS OF EXPERIMENT 2

The aim of the second experiment was to find out, as the results of the first experiment suggested, whether writers using Page would benefit significantly from the possibility of building a better representation of text content and text structure, and from easier navigation through the text. This led to the prediction that Page writers would be more efficient at diagnosing and correcting coherence problems in a text.

Mobility within the text. The results of Experiment 2 indicated that compared to Scroll, Page writers more often went beyond the limits of the portion of text displayed on the screen, as their higher number of backtracking sequences showed. Participants were able to link distant parts of the text in order to diagnose coherence problems that could only be detected by going back and forth through the text.

Text improvement. The improvement of the surface aspects and cohesion of the text did not depend on the way writers moved around in the text. Almost all surface errors were corrected. Writers had more trouble improving text coherence, with Page and Scroll alike. Not all coherence errors were corrected. However, coherence revisions by Page writers *(50%)* significantly outnumbered those of Scroll writers *(31%).* In addition, Page facilitated the correction of coherence errors which required verifying and accessing two "places" in the text that could not be viewed at the same time. Thus, the different text dynamics offered by Page and Scroll definitely impinged on the quality of writers' processing.

8. Conclusions

From a purely behavioral standpoint, both readers and writers performed more actions when working in Page than in Scroll. Indeed, both groups of participants moved around more with Page than with Scroll. At the cognitive level, the processing carried out by Page participants was also of a better quality. Page readers had a better grasp of text content due to their greater reliance on regressions and their use of the spatial features of the text which, like book reading, were presented in page format. Revisers also benefited from the greater mobility offered by Page for discovering and solving the more difficult problems in the text. Results reported above are compatible with the statements raised in the comprehensive review made by Dillon *(1992).*

Thus, the results of these two studies may suggest that a page-based system rather than the scroll-based one allows participants to build what Hansen and Haas *(1988)* or Severinson Eklundh *(1992)* called a better "sense of text". However, the effects of the factors likely to have an impact on tangibility, responsiveness and disruption of the spatial layout were not directly evaluated here. Future experiments using other kinds of prototypes are needed to determine the impact of these factors. The effect of page numbering via icons, e.g. could be studied in order to separate this information from information about the spatial layout of the text on the page. Furthermore, Experiment *2* did not allow us to determine how the Page system facilitated the correction of coherence errors in the text. Were the Page writers better at improving text coherence because they detected more incoherence or was it because the Page system made revising operations easier (especially moving portions of text)? A task where participants would merely have to read the experimental text and indicate verbally where they detected coherence errors would enable us to decide between these two possibilities.

Finally, because it is the tradition in the world of writing, the presentation of information in paginated spaces (better spatial encoding in the Page prototype than in Scroll) offers readers and revisers easier means for reading and working on texts. The present findings should provide incentive and ideas to ergonomists for improving the management of dynamic text on the screen. We believe that a better knowledge of the interaction between text display, manipulation facilities and subsequent reader comprehension and ease of editing constitutes a hot topic, because of the growth of the Internet and the emergence of digital libraries. However, given the massive spread and use of scrolling, it is also important for psychologists, whose goal is to account for participants' information processing, to determine what cues readers and writers detect or devise to adapt their technique to this particular type of dynamic text. In other words, future investigations should check the relations between presentation mode and the various degrees of spatial abilities among word processor writers.

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Appendix 1

Screen in Scroll presentation showing the beginning of the text. Screen in Page presentation showing text page 3 (see Figure 1).

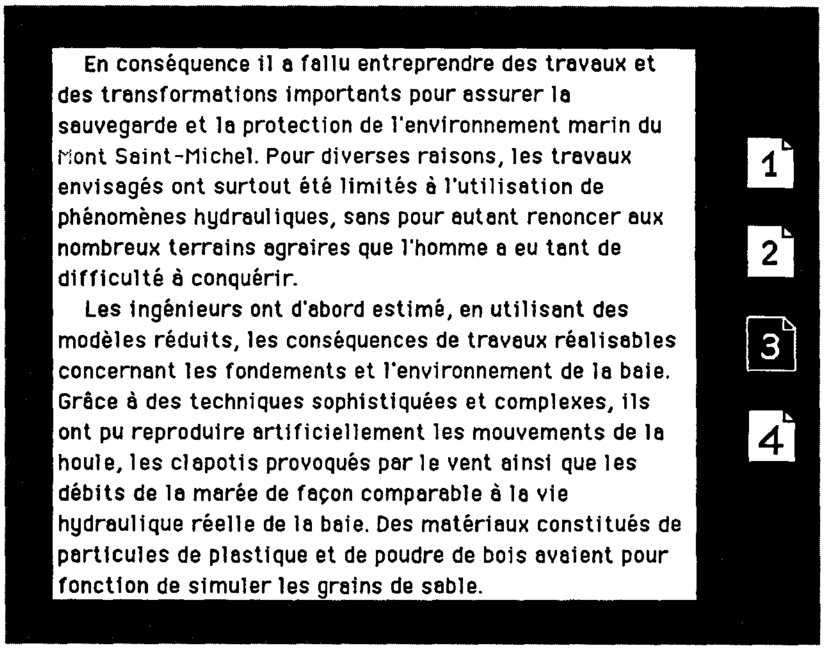
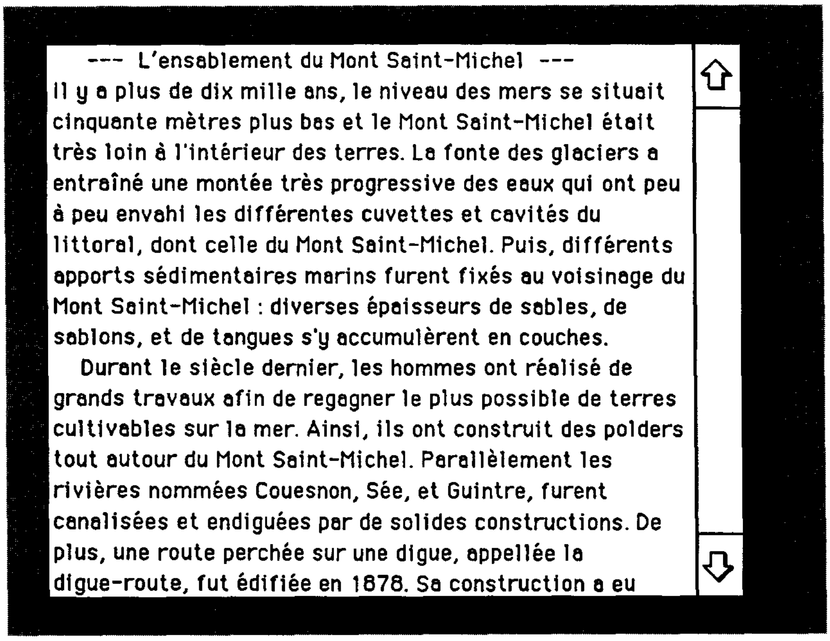


FIGURE 1

Page-break system and No-page-break system (Figure 2).



--- L'ensablement du Mont Saint-Michel ---
Il y a plus de dix mille ans, le niveau des mers se situait cinquante mètres plus bas et le Mont Saint-Michel était très loin à l'intérieur des terres. La fonte des glaciers a entraîné une montée très progressive des eaux qui ont peu à peu envahi les différentes cuvettes et cavités du littoral, dont celle du Mont Saint-Michel. Puis, différents apports sédimentaires marins furent fixés au voisinage du Mont Saint-Michel : diverses épaisseurs de sables, de sablons, et de tangues s'y accumulèrent en couches.

Durant le siècle dernier, les hommes ont réalisé de grands travaux afin de regagner le plus possible de terres cultivables sur la mer. Ainsi, ils ont construit des polders tout autour du Mont Saint-Michel. Parallèlement les rivières nommées Couesnon, Sée, et Guintre, furent canalisées et endiguées par de solides constructions. De plus, une route perchée sur une digue, appellée la digue-route, fut édifiée en 1878. Sa construction a eu

FIGURE 2

Appendix 2

Page-break system and No-page-break system.

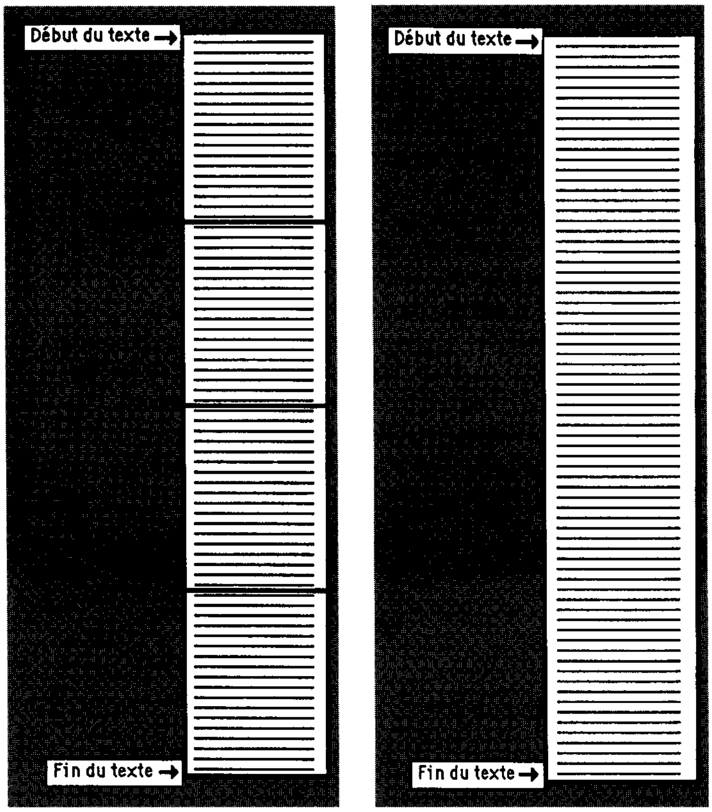


FIGURE 3

Appendix 3

Screen of the mini-word processor in Page presentation.

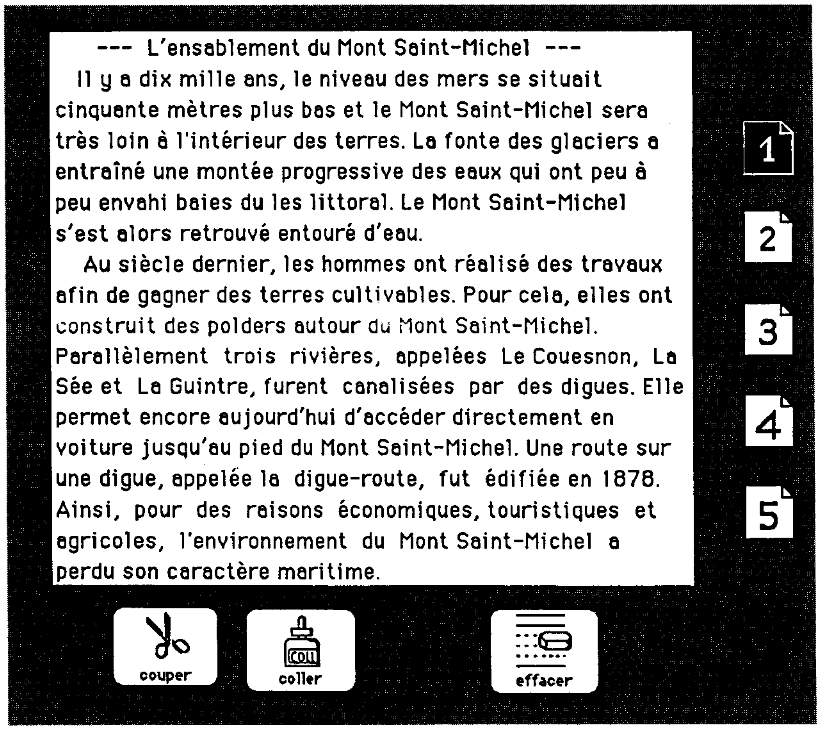


FIGURE 4